MAY 1956

Journal
of
The Franklin Institute

1826

1956

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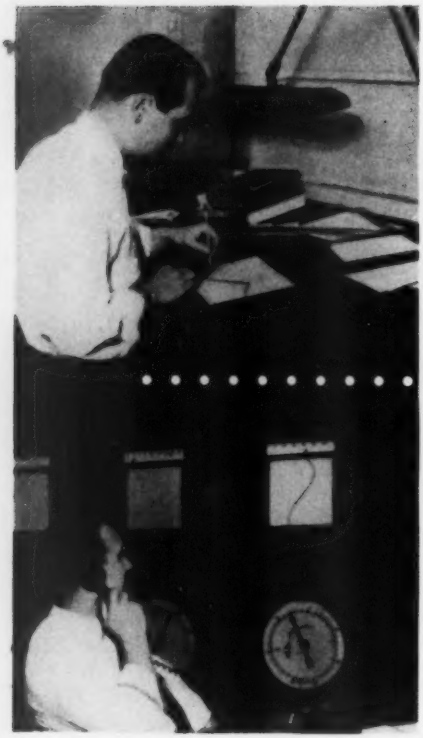
VOL. 261 NO. 5



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Entered as second-class matter March 14, 1928, at the post office at Lancaster, Pa., under act of March 3, 1879. Acceptance for mailing at special rate of postage provided for in paragraph (d-2), section 34.40, P. L. & R. of 1948, authorized on July 3, 1919.

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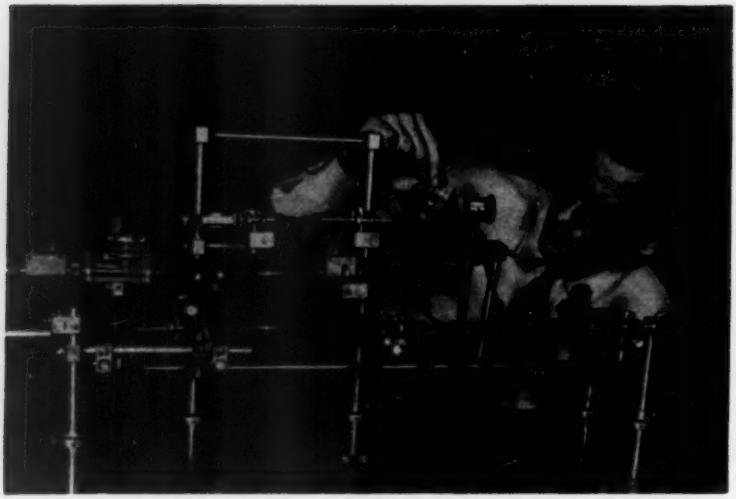

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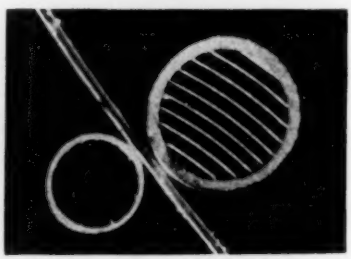

Grids in new tube, enlarged 30 times, with human hair for comparison. Electronic beam passes through smaller, then larger, grid.

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Published monthly by The Franklin Institute of the State of Pennsylvania, Benjamin Franklin Parkway at Twentieth St., Philadelphia 3, Pennsylvania. Printed by Lancaster Press, Inc., Prince and Lemon Sts., Lancaster, Pennsylvania.

Subscription rates: Domestic, $10.00 a year; Foreign, $11.00 a year. Single current issues, $1.00. Reprints, 50 cents per installment. All inquiries regarding subscriptions, change of address, sale of back issues and reprints, should be addressed to the Philadelphia office.

Indexes to the semi-annual volumes of the JOURNAL are published in the June and December numbers.

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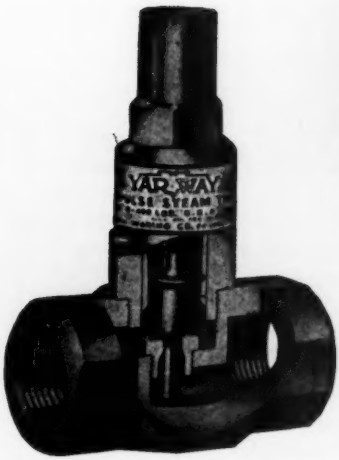

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Vol. 261 MAY, 1956 No. 5

DANGER! THE RADIO SPECTRUM IS BURSTING AT THE SEAMS *

BY

DONALD G. FINK [1]

If the title of this paper appears to fall in the "scare headline" class, that is indeed the intended effect. The danger is very real. Overshadowing the truly impressive technical progress of radio communication, broadcasting and the related arts lies a warning signal, the ever-increasing shortage of space in the radio spectrum. Scores of vital services are crammed into inadequate channels, each bedeviled by increasing levels of interference. The situation grows worse with every passing month, and there appears to be no prospect of relief.

As a concrete example, consider the situation of millions of rural American families who lie beyond range of television stations and who maintain contact with the world of news and entertainment primarily through standard broadcast (a-m) stations. There are at present 2850 a-m stations in this country crowded on 106 channels. It is no exaggeration that 2700 of these stations are of no use whatever to rural listeners at night, because they are blocked off by overwhelming interference from other stations operating on the same frequencies. Fortunately, a number of a-m channels are reserved for so-called "clear-channel" stations, meaning that no more than four or five stations are permitted to occupy such channels. They can reach out to audiences over 1000 miles or more, in most directions, at night. But as a general rule, at night, radio sets must be tuned to clear channels or to stations within 50 miles. Otherwise the effect is a bedlam of heterodynes and monkey chatter.

Other examples could be quoted by the score. The unequitable distribution of television stations, arising wholly from the shortage of

* Lecture presented at a joint meeting of the Philadelphia Section of the IRE and The Franklin Institute, February 1, 1956, in the Lecture Hall of The Franklin Institute.

[1] Director of Research, Philco Corporation, Philadelphia, Pa.

(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors in the JOURNAL.

v-h-f television channels, has assumed the proportions of a national scandal. The Senate has in fact started a full-dress investigation of television allocations, as of January, 1956.

Even the small business man is caught in the shortage. For example, using radio dispatching, a taxicab company can so improve its operations as to put competing companies out of business, unless the competitors also set up radio facilities. So the taxi-radio bands have become crowded, so crowded that the johnny-come-lately among taxi companies may find itself a total victim of technological progress—crowded out by the shortage of spectrum space.

These troubles, and many more like them, have forced upon the radio industry a belated realization that the radio spectrum is a natural resource, a public domain of limited extent, which must be administered as wisely and guarded as jealously as if it were mineral wealth, water-power, or forest land.

The need for a program of spectrum conservation is evident enough; but a complete working program, involving all available technical and political resources, does not exist. The general features of such a program must be laid out and specific corrective measures agreed to before the public and private uses of radio can expand to the full measure of future needs. Moreover, if the program is to be effective, the conservationists, the responsible frequency-allocating and policing agencies throughout the world, must enforce the corrective measures with singular wisdom and courage, against the organized pressures that fought conservation measures, in favor of special interest, since governments began.

It may well be questioned why the dangers of the spectrum shortage should be brought before the IRE and The Franklin Institute. First, the membership of these bodies contains many men, engineers, scientists and men in public life who can contribute very substantially to the conservation program. Second, and most important, the solutions to the spectrum problem must be based on understanding of the technical past and the technical present. Unless the conservation program is based on sound technical doctrine, it will surely misfire, and the present opportunity to correct allocation abuses may be lost in increasing chaos for decades to come.

Much of the discussion presented here is based on the book "Radio Spectrum Conservation," prepared in 1952 by the Joint Technical Advisory Committee and distributed by IRE and RETMA to those intimately concerned with spectrum administration, as well as to the principal technical libraries of the world. Despite the fact that the writer had a part in the preparation of this book, he does not hesitate to recommend that it be taken from the library and read with care by every engineer whose livelihood depends on the continued health of radio communications in any of its branches.

Let us start, then, with a brief review of what is at stake. In Table I are shown the end uses of radio presently recognized by the Federal Communications Commission. In all there are 83 such uses.

TABLE I.—*End Uses of Radio.*

Communication Purposes

1. *Fixed Services*

Aeronautical fixed	Petroleum
Remote pickup	Relay press
Studio-transmitter link (standard broadcast)	Special industrial
Studio-transmitter link (FM broadcast)	Highway truck
Studio-transmitter link (television broadcast)	Intercity bus
Television intercity relay	Railroads
Television pickup	Urban transit
Citizens' radio	Fire
Miscellaneous common carrier	Special emergency
Fixed public (international)	Forestry conservation
Fixed public (domestic)	Highway maintenance
Forest products	Police
Motion picture	State Guard
Power	Government

2. *Mobile Services*

Aeronautical advisory	Automobile emergency
Aeronautical land	Highway truck
Aircraft	Intercity bus
Airdrome control	Railroads
Flight test stations	Taxicab
Flying schools	Urban transit
Remote pickup	Coastal harbor
Television pickup	Coastal telegraph
Citizens' radio	Coastal telephone
Domestic public mobile	Ship telegraph
Miscellaneous common carrier	Ship telephone
Forest products	Fire
Low-power industrial	Forestry conservation
Motion picture	Highway maintenance
Power	Police
Petroleum	Special emergency
Relay press	State Guard
Special industrial	Government

3. *Broadcast Services*

Developmental broadcast	High-frequency (international) broadcast
Educational (FM) broadcast	Standard broadcast
Experimental facsimile	Television broadcast
Facsimile broadcast	Government
FM broadcast	Experimental broadcast

4. *Amateur Services*

Amateur

5. *Special Services*

Special service bands are not allocated. However, a number of government and non-government services would logically be placed in such bands within the terms of the Atlantic City definition for this service.

Table I. (*cont.*)

Location and Ranging Uses

1. *Radiolocation Services*
   Radiolocation
2. *Navigation Services*
   Aeronautical radar
   Shipboard radar
   Government
3. *Special Services*
   Government

Industrial and Scientific Uses

1. *Industrial, Scientific, and Medical Uses*
   Medical diathermy
   Industrial heating
   Miscellaneous

Only in terms of such specific applications can spectrum conservation be visualized concretely as an urgent, real problem. It involves every channel of commerce, the operation of all modern forms of transportation, protection of life and property, and the education and entertainment of hundreds of millions of people. So visualized, the present emergency is no academic matter.

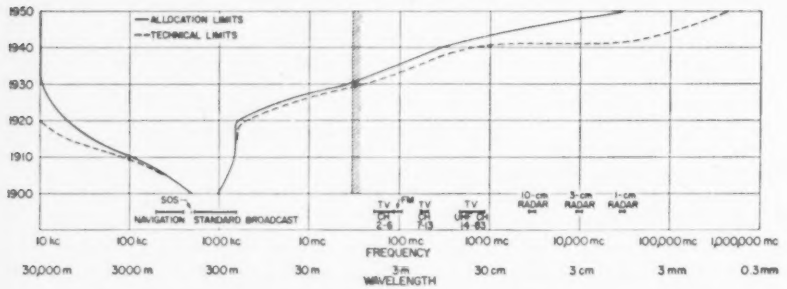

Fig. 1. Growth of the radio spectrum 1900–1950 (logarithmic frequency scale).

Figure 1 illustrates the growth of the spectrum over the period 1900 to 1950. At the bottom we have the frequency and wavelength scales, plotted in eight logarithmic decades from 10 kilocycles to 1,000,000 megacycles, and the corresponding wavelengths from 30,000 meters (18 miles!) to 0.3 millimeter. Another six decades of frequency take us through the infrared, visible and ultraviolet radiations to the x-rays, and a further four decades reach the outer limits of cosmic radiation.

The top of the chart illustrates the spectrum as we know it today. At the bottom, back in 1900, when wireless first found use on shipboard,

the radio spectrum was not a definite concept and no one was quite sure what frequency was in use. Two calling frequencies, 500 kc. and 1000 kc., were nevertheless identified and allocated in 1906. In those days the antenna itself was the frequency-determining element of the transmitter, and the limits of the spectrum were based indirectly on the physical space available for antennas aboard ship.

By 1910, other means of tuning were available, and fixed stations had been allocated frequencies as low as 100 kc. and as high as 1500 kc. Technical knowledge, whose limits are indicated in Fig. 1 approximately by the dashed lines, then showed the way to expansion toward still lower frequencies. By 1920, frequencies of 20 kc. were allocated and in 1930 the lower limit of 10 kc. was reached. Here technical and economic limits appeared. At these frequencies it takes two mountain peaks to support a really efficient antenna and atmospheric interference is especially severe. So, since 1930, there has been no reason for extending the lower limit of the spectrum.

Not so in the direction of higher frequencies. For a decade the high-frequency limit of the spectrum was stalled at 1500 kc. because the experts were certain that wavelengths shorter than 200 meters were completely useless, fit only for the amateurs. These hardy souls, by the early 1920's, were busy proving that the experts were ordinary mortals from out of town. In the next ten years, 1920–1930, a new frequency decade was added to the useful spectrum. From 1930 to 1940, nearly two more decades were explored, and from 1940 to 1950 still another two and a half decades were revealed to radio science. The allocations (solid line) followed rapidly behind the new technical knowledge. By 1950, the official FCC allocation extended to 30,000 megacycles, while the scientists have been busy with millimetric waves extending almost to a mega-megacycle.

Located on this chart are a few of the best known radio services. The SOS distress and calling frequency at 500 kc., set up in 1906, has remained there ever since. The navigation and beacon band from 200 to 415 kc. has given yeoman service to marine and aviation interests, although it is now obsolescent. The standard broadcast band lies between 540 and 1600 kc. Television and f-m broadcasting appears above the "shortwave region"; u-h-f television is still higher. Microwave radar occupies frequencies in the 1, 3, and 10 centimeter-wavelength range, as shown.

It should be noted that, on this logarithmic frequency scale, v-h-f television appears to consume less space than standard broadcasting, although the v-h-f TV band is actually nearly 75 times as wide as the broadcast band. This proves only that the logarithmic scale is faulty for representing spectrum occupancy. However, a linear frequency scale is not of any particular help. Figure 2 shows the spectrum-growth diagram redrawn in linear fashion. In it, the entire known

spectrum, prior to 1940, is completely hidden at the edge of the figure, below 200 mc.

It is evident from Fig. 1 that an enormous expansion of the spectrum has occurred from 1900 to the present. In fact, the total frequency space allocated by 1950 was 60,000 *times* as much as in 1906 and roughly 1000 times as much as was allocated in 1930. Where then is the spectrum shortage? Certainly from the viewpoint of the allocations expert of 1930, the expansion which has since occurred should have taken care of all contingencies. Why, indeed, is a spectrum eight frequency decades wide too restricted for present needs?

There are many reasons why the spectrum expansion has provided little opportunity for a corresponding expansion of radio services. Perhaps the most fundamental is that the new frequencies do not possess many important transmission properties of the old. This is

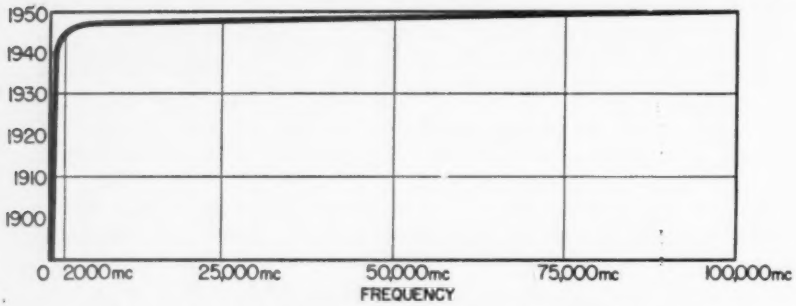

FIG. 2. Growth of the radio spectrum (linear frequency scale).

illustrated by the boundary shown in Fig. 1 at approximately 30 mc. Frequencies to the left of this limit have the ability to cover global distances, of the order of thousands of miles, in a single hop. These are the frequencies which must be used in the ocean-spanning services and wherever it is necessary to serve economically a widely dispersed audience. Frequencies to the right of the boundary, with some exceptions tied in with the sun-spot cycle, are not global in application; they are strictly local, covering a few hundred miles at most unless extremely high power and pin-point directionality are used. This means that only 30 mc. out of 1,000,000 mc. can be used for long-distance, single-hop circuits. Consequently, the frequencies below 30 mc. are particularly crowded.

A second contributor to overcrowding, despite the newly available frequencies, is the fact that many of the newer services, notably f-m broadcasting, television and radar, require channels substantially wider than those of the older services. An f-m station occupies 20 times as much spectrum space as an a-m station; TV stations use 600 times as

much. A radar station takes up to several thousand times the spectrum space needed for a radio teletype circuit.

When one of these wideband services finds an important place in the public favor, as has television, its demand for spectrum space may quickly reach epic proportions. In the United States today 82 television broadcasting channels are available for assignment, each 6 mc. wide—a total of 492 megacycles. This reservation of space for television alone exceeds by 20 times the whole extent of the radio spectrum as it was known prior to 1930.

Thirdly, the upper headwaters of the spectrum, above 10,000 mc., are beset by peculiar natural difficulties. Attainable transmitter power is low in this upper region, as is receiver sensitivity. At certain frequencies, the atmosphere develops a murky opacity, due to internal resonances in gas and vapor molecules. Above 30,000 mc. a good hard rainstorm can attenuate the circuit right out of existence, and few services can afford to be classified as "fair-weather only."

The fourth contributor to spectrum density, despite spectrum growth, is a social disease which goes under the general title of "The Dead Hand of the Past." Owners and operators of radio equipment, not only the "big interests" but the man in the street, like to think of themselves as prudent investors. When a new region of the spectrum, suitable for an overcrowded service, shows up, newcomers to that service may well be persuaded to establish their homesteads in the new territory.

Not so the established inhabitants. They pull every string in the political economy to avoid wholesale obsolescence of their equipment. This goes for us, everyone in the audience who owns a television set. Imagine the protest that would greet any plan to shut down the TV stations in Philadelphia and Wilmington and transfer the service to the u-h-f band. This might have beneficial effects, particularly to those possessing u-h-f construction permits, but a 25-dollar charge for conversion from v-h-f to u-h-f would thereby be handed a million local families, with no option if they ever wanted to see Howdy Doody again. Multiply this aversion to change in the television service by a similar attitude in 82 other end uses of the spectrum and you form a fair picture of the problems of administering the growing structure of the radio arts.

This steadfast maintenance of the status quo is no new tendency. The standard a-m broadcasting band is a good example of a service pushed over by the Dead Hand. Broadcasting would be very substantially better, from the standpoint of coverage of audiences over hundreds of thousands of square miles, if the band were extended downward from its present lower limit of 540 kc. to, say, 200 kc. But the space between 200 and 540 kc. was pre-empted by the maritime and point-to-point services in the early 1920's, when a-m broadcasting

began. At that time there was no other spectrum space for the marine frequencies, and broadcasting was new. So broadcasting took the next best spot, frequencies above 540 kc.

Today, there are several alternative solutions to the marine service, particularly in coastal waters. But the shipping masters will have precious little of any of them. After all, shipboard receivers and transmitters that have lasted 20 years must be reliable. Why change?

Another example: The land-mobile services, including the frequencies used by police and fire departments, got started in the neighborhood of 2000 kc. These frequencies are suitable for local service during the day but at night they are subject to serious interference from considerable distance. Frequencies above 40 mc., equally suitable for local operations and comparatively free of long-distance interference, were made available at a later date. New police installations have by and large been confined to these higher frequencies and many of the older land-mobile systems moved into the new territory.

One might think this would have freed the space about 2000 kc. for other services. Not so. The land-mobile bands in that area are still in use, mainly by state police systems.

The Dead Hand lies clammily in many another spectral arena. The aviation beacon band service, from 200 to 415 kc., is a first class anachronism. Better radio range systems are available, and in regular use by the airlines and private flyers, at frequencies of 75 mc. and up. But the old fashioned A-N radio range beacon is still with us; it's dead but it won't lie down!

These technical and politico-economic causes of spectrum crowding are but symptons of the grand malaise, which is simply an overpowering increase in the applications of radio transmission to every phase of personal living, commerce and industry. Let us repeat, there are no fewer than 83 recognized end uses of radio. If the National Association of Manufacturers has its say, there will soon be several more, having to do with radio control and communication *within* manufacturing plants.

Briefly stated, the people of the world want more rapid and cheap communication, they want more entertainment, they want better goods and services of every kind and description. It turns out that radio science is a prime tool in providing all these. So, everyone wants in the act.

What can be done about it? The body politic, having tasted the fruit of radio and television broadcasting, worldwide telephone service, vastly faster aerial, marine and surface transportation, and so on and on, is certainly not going to reduce the pressure. Increased demand on the spectrum is certain. Faced with this certainty we must find, and use, the means so to increase the efficiency of spectrum occupancy that we can meet the demand as fully as possible.

If we really want to relieve congestion in the spectrum what would we do, given a completely free and dictatorial hand? Try these on for size:

1. We would completely decentralize cities and eliminate concentrations of population, since the short-range radio services are crowded primarily because so many stations have to be put in or near cities.
2. We would put everyone, in personal life as well as in the office, farm and factory, on three shifts. This would put the services to use on a favorable duty factor, instead of crowding them into a 9-to-5 business day, and a 7-to-midnight relaxation period, with eight hours out for sleep.
3. We would install a permanent peace. The military now has jurisdiction over hundreds of megacycles of spectrum space that could thereby be assignable to peaceful pursuits.
4. We would eliminate competition and install government price fixing and program censorship in its place. This would remove duplicate facilities and wasteful operating procedures, which seem to be inevitable even in the most benign of competitive systems.

None of these propositions (except, we hope, enduring peace) is in prospect for the foreseeable future; they have been propounded merely to show the extent to which the congestion of the spectrum depends on the social structure of our times. They illustrate the fact that the spectrum is not only occupied in a frequency sense, but in geography and time as well. The occupancy in space and time is largely governed by concentrations of population and by habits of daily living, of doing business and by national policy. These factors are not amenable to control, in any large degree, in any plan of spectrum conservation.

But I would like now to add a fifth item to our list of the actions that might be taken to relieve congestion, given a free hand:

5. The essential value of each service utilizing radio propagation would be periodically reviewed against a broad standard of the public interest, convenience and necessity. Those whose value was on the wane would be required, after a decent interval, to give up their frequency allocations in favor of new services whose value, by the same standard, outweighed the old. The "decent interval," during which the transition would take place, might vary from two to twenty years, depending on the nature of the investment (that is the amount and by whom invested) in equipment and the rate of technical obsolescence of the equipment.

This fifth proposition *is* in prospect for the foreseeable future. Only by adopting it can the Dead Hand be put honorably to rest where it belongs, six feet underground. Some such dynamic review of spectrum values, as the art progresses and the needs of society

change, is absolutely necessary if we are to make optimum use of the spectrum in the years ahead. Moreover, this is the kind of proposition which, if not adopted voluntarily by the free enterprisers who exploit the spectrum for public and private good, will eventually be forced upon them by legislative process.

So much for the social limits of spectrum reform. What are the technical limits? Consider first the annoying fact that communication systems thrive only when they possess signal-to-interference ratios substantially higher than unity. It is true that, in sending a night-letter, you might pull the message through overwhelming interference if indeed you take all night to correlate the message signal components. But this so injures the time occupancy of the circuit that, in practical terms, such advanced techniques are not useful. Rather, the signal should be anywhere from 10 to 50 db. above the interference, if it is to fulfill its intended destiny.

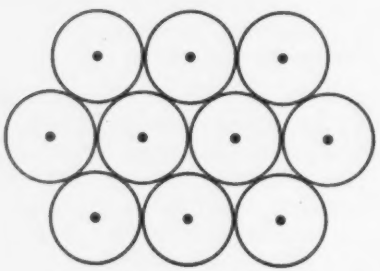

FIG. 3. Radio coverage of population centers, if interference radius were equal to service radius.

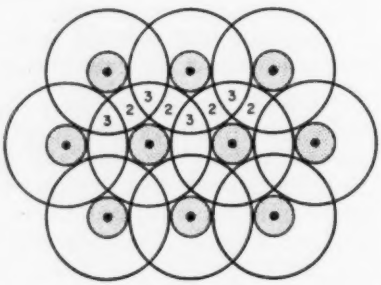

FIG. 4. Service areas (shaded circles) and interference areas, when interference radius is three times service radius. Numerals indicate the number of interfering signals.

The inescapable corollary of this proposition is that radio stations by and large create interference over greater distances than they render service. This means that two stations, occupying the same frequency, are always separated by an interference-filled zone within which service is available from neither.

The effect of this zone on geographical occupancy is illustrated in Figs. 3 and 4. Figure 3 shows ten population centers evenly distributed, each to be covered by a transmitter using the same frequency as its neighbors. If the interference and service radii of transmitters could be made to coincide (in contradiction of the proposition just cited), each city and its environs could be served by a transmitter located at the center of population, with its power so adjusted that the respective coverage zones were just adjacent. No interference would occur; the coverage would be very nearly complete.

This is a nice trick if you can do it. But it seems to be completely ruled out by the signal-to-interference proposition stated above. Rather, the situation in real life has to be treated as in Fig. 4. Here we suppose that each transmitter creates interference, against a similar transmitter on the same frequency, over a radius three times as great as its service radius. This is a realistic assumption in ground-wave broadcast services, and is very close to the situation obtaining in the v-h-f television service.

Now we find that service is rendered only within the small shaded circles, against which the interference contours of the adjacent stations rest. All the rest of the countryside resides in zones suffering interference among two or three stations at once. Comparison with Fig. 3 shows that the useful coverage of the stations has been reduced to one quarter of what it might be if the service and interference radii could be made to coincide. The three quarters of the service thereby wiped out is, to be sure, in the outskirts of each community, where the population density may be expected to be small. But it illustrates the general discrimination against rural and suburban populations caused by the signal-to-interference requirement.

This discrimination takes place when the conditions of propagation are unvarying, but it is made considerably worse if the signal strengths vary from hour to hour, day to day, or season to season. The service and interference areas do in fact vary with the condition of the atmosphere, particularly the condition of the ionosphere for frequencies below approximately 50 mc., and of the troposphere at frequencies above 50 mc. These variations may be of great magnitude, they may be sporadic or periodic, and they are almost impossible to predict in detail.

Two results of these phenomena are of importance. In the first place, the *occasional* interference range of a transmitter, during exceptional conditions of long distance transmission, is very much greater than the *reliable* range of service, which must depend on normal propagation. The net effect is an even wider geographical separation between stations on the same frequency than would be suggested by Fig. 4.

In the second place, the diurnal and seasonal variations of propagation, particularly of frequencies below 25 mc., require the assignment of several frequencies to many classes of station, only one frequency of which is in use at a time, depending on the time of day or season and the distance to be covered. The frequencies assigned but unused at a particular time can be used by other stations only if a carefully coordinated program of sharing frequencies is instituted. The result is a frequency and time occupancy of the spectrum far below that which would obtain under steady conditions of propagation.

Neither of these technical hindrances to full spectrum occupancy

can be controlled, so far as the basic mechanisms go. The signal to be useful must be well above the interference, and the ionosphere and troposphere must be allowed to pursue their devious ways. But, fortunately, techniques can be applied to limit the *extent* over which these hindrances operate.

One such technique is the use of directive antennas at transmitter or receiver, or both. The general proposition may be stated thus: Signals should be transmitted only in the directions of the intended users and signals should be received only from the direction of the desired station. If this dual principle could be applied in a thoroughgoing way, a large part of the congestion of the spectrum would disappear overnight.

Applying directivity is, of course, not an easy or simple matter in many cases. Broadcast stations located directly at a center of population, such as the seven television stations atop the Empire State Building in New York, must presumably radiate uniformly in all directions, since those are the directions in which the customers live. But if broadcast transmitters are located to one side of, or between, population centers, great advantage can be taken of directional radiation.

One example familiar in these parts is the a-m transmitter of WOR, which was moved about twenty years ago a substantial distance to the southwest from the vicinity of New York to Cartaret, New Jersey. A two-way directional antenna system was installed having its major lobe of radiation lying on the axis connecting Boston, New York, Philadelphia and Washington. This arrangement produced a strong signal in New York, but covered Philadelphia also, in such a manner in fact that this station can compete on an almost equal footing with the local Philadelphia stations. Interference to the west was appreciably reduced and, into the bargain, less power was wasted on the unpopulated reaches of the Atlantic Ocean. Countless other examples of directional systems exist in a-m broadcasting; but they are very rare in television broadcasting.

Directivity in receivers is also available. Most a-m radio receivers of the present day display some directivity by virtue of the built-in loop antenna, but this is not of sufficient sharpness to discriminate against interference from other stations to any great extent. Television receiving aerials can be made to have very high directivity, which, in conjunction with a rotating mount, can be used very effectively against interference.

Directivity is also widely applied in point-to-point communications, much less so in mobile work. It can, and should, be used much more widely than it is, in virtually every branch of the radio art.

Thus far we have been concerned with the technical problem of many stations operating on the same frequency with a minimum of mutual interference. It is equally important that each station should

use as little space in the spectrum as possible. This leads us into the questions of sidebands, guard bands and frequency tolerances. If we are to have maximum spectrum occupancy, the sidebands should be as narrow and as densely packed with significant and unduplicated information as possible, and guard bands and tolerances should be reduced to the vanishing point.

Consider first the width of the channel assigned to a particular service and the degree to which the channel is filled with sidebands. It would appear to be most efficient if each channel should be filled

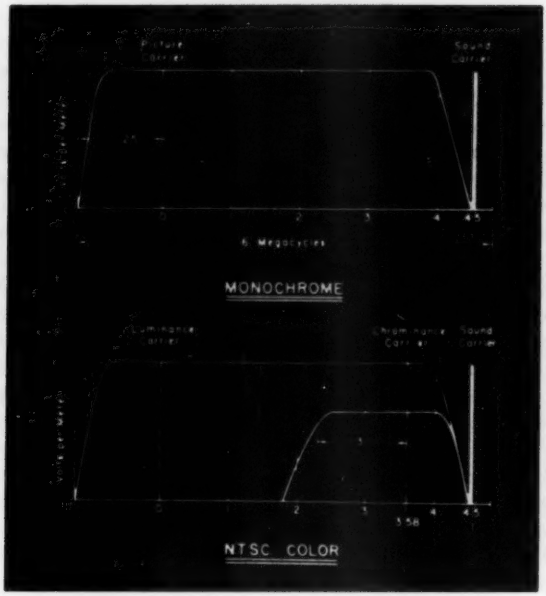

FIG. 5. Comparison of signal spectrum for monochrome (top) and compatible color television broadcast channels.

edge to edge chockablock with differentially adjacent sidebands. But such a sideband structure could convey no intelligence whatever; it would in fact represent completely featureless noise. In point of fact, all useful methods of modulation involve concentrations of energy at particular regions of the channel occupied. This fact is a fundamental postulate of information theory and cannot be circumvented. Consequently no station can occupy its channel continuously and uniformly. But there are nevertheless wide differences among methods of modulation regarding the density of the sidebands. In some services, the sideband density can be increased with resulting improvement in

spectrum occupancy, by suitable choice or manipulation of the modulation method.

Compatible color television is an excellent case in point. The compatible color signal consists of a conventional black-and-white signal to which a supplementary signal, which carries the coloring information, has been added. The color signal is not added, however, by widening the channel, since this would destroy the compatibility of the system. Rather, it is added *within* the existing channel, superimposed directly on the black-and-white signal, as shown in Fig. 5.

Interference between these two signals would have been thought inevitable only a few decades ago. Today we know different. We know that gaps exist in the black-and-white signal spectrum and that similar gaps exist in the coloring signal. Moreover, since both signals arise from the same scanning source within the camera, the gaps occur at precisely the same points in the spectra of the two signals. So if one signal is moved over with respect to the other by one-half the distance between gaps, the energy concentrations in one can be made to fall precisely in the gaps of the other, and the two signals can be transmitted simultaneously without undue mutual interference.

It must be noted that the success of this unique doubling up of channel occupancy depends on several special circumstances, of which the particularly redundant nature of scanning is one, and the persistence of vision of the eye, in viewing the final result, is another. But it works. Because it works, color has been added to black-and-white television with no increase in spectrum congestion whatever—a truly remarkable example of what can be done.

During the past ten years modulation methods have been given a great deal of study, to determine how efficiently they employ the channel occupied. We know now that amplitude modulation has little to recommend it, that certain forms of pulse-code modulation are theoretically the most efficient and that frequency modulation ranks high on the list.

Modulation methods have progressed also in the direction of suppressing the transmission of superfluous signals, that is, signals which are mere duplicates of other signals already present. The picture signal in both black-and-white and color television is transmitted by vestigial sideband, cutting out about 3 mc. of channel width that would otherwise be filled with duplicate sidebands. In still more advanced modulation schemes, the carrier and one complete sideband are completely suppressed. Such single-sideband schemes have permitted three or four point-to-point telephone circuits to be set up in the space once occupied by one double-sideband circuit. The amateur operators have found single-sideband transmission a godsend in the super-crowded telephone ham bands. But such efficient systems of modulation are not as widely used as they should be. They deserve a substantial place in any plan of spectrum conservation.

It might be expected, once the sideband structure of a given service is understood, that the channel width should be chosen so as just to enclose the limits of the significant sideband energy. In many services this is true. In fact, in standard a-m broadcasting, audio modulation above 5 kc. is permitted and this produces significant sideband energy outside the limits of the 10-kc channel. At a distance, this produces an adjacent-channel interfering effect known as monkey chatter. The monkey chatter effect is avoided in local reception by assigning a-m stations in the same locality no closer than 50 kc.

A similar tailoring of sideband content to channel width is the rule in f-m and TV broadcasting, and the carrier frequency tolerances are narrow. For example, on compatible color broadcasts, both sight and sound carriers must be held within plus or minus 1000 cps., and this represents a tolerance of only a part in a million at channel 83.

However tight the situation may be in broadcasting, other services have channels substantially wider than the sideband content, the extra width being provided for carrier tolerance and selectivity of receiver tuning. For example, in the land mobile band in the neighborhood of 150 mc., the channel width is currently 150 kc., and in the same service in the 400 mc. band, the channel is 200 kc. wide. In either case, the useful sidebands certainly do not occupy more than 10 kc. at the most. This is a gross abuse, justified only by the cost of improving transmitters and receivers. Actually, at present, the FCC has under advisement changes in the rules to reduce these channels to 50 and 100 kc., respectively, with evident benefit to the spectrum economy.

These examples illustrate some of the technical measures available to improve spectrum economy. In sum, they offer a substantial contribution to the solution of radio's most pressing problem, but they are not being used to the extent required. As outlined in the JTAC book previously mentioned, the following specific measures are recommended by that body to implement a dynamic program of spectrum conservation:

"The limitations governing spectrum occupancy discussed [in the previous paragraphs] suggest a number of corrective measures, some rooted in the design and operation of technical equipment, others in the administration of allocations. The technical measures comprise the early adoption of methods contributing to spectrum conservation, with due regard for the benefits and costs involved. The administrative steps involve applying sound doctrine in comparing the economic and social values of competing services.

"In adopting these measures, great care must be exercised to avoid foreclosing future developments. The cornerstone of the conservative program should be the encouragement of and, as far as possible, advance provisions for new services having more extensive or comprehensive values than the old. Such unborn methods and services may have, in fact, at least as important claims on our natural resources as

the services currently occupying the spectrum. The evaluation of the relative importance of the old and the new is, in fact, the most delicate task in the administration of the spectrum.

"The following suggestions are offered, therefore, on the assumption that necessary steps have been taken and are in continuous effect to encourage experimentation with new services throughout the spectrum. The suggestions apply in particular to services which have passed the experimental stage and have entered or are about to enter regular operation.

"On this basis, the following measures are indicated:

"1. Experimental authorizations to develop new services should be granted in all regions of the spectrum, subject to reasonable safeguards to prevent interference with existing services. When a radio service performs a function which can be performed by nonradio equipment (e.g., wire lines), the permanent establishment of the radio service, beyond the developmental period, should not take place until the comparative costs and values of the radio and nonradio services have been assessed and compared and a determination made of other demands on that portion of the spectrum. Unless the costs of the radio service are appreciably less or their value appreciably greater than the corresponding costs and values of the nonradio service, conservation of the spectrum requires that nonradio services be used.

"2. The frequency tolerances applicable to carrier emissions should be a suitably small fraction of the channel width. In most cases 'suitably small' implies as small as the state of the art permits, without incurring undue penalties in size, weight, or ease of operation and maintenance. Such penalties are not usually the controlling factor. The principal deterrent is cost. After a reasonable period to amortize the cost of substandard equipment has intervened, it should be replaced by equipment meeting a reasonable standard of carrier stability.

"3. Off-frequency operation and pirating of frequencies represent a gross derogation of the principles of spectrum conservation which must be brought under control by improved methods of international cooperation.

"4. The use of guard bands to accommodate apparatus deficiencies (such as excessive carrier-frequency tolerances, improper or inefficient transmitter modulation, or inadequate receiver selectivity) should be curtailed.

"5. The use of the most efficient modulation methods, with respect to uniform frequency occupancy of the assigned channel, should be encouraged, particularly in the wideband services such as f-m and television broadcasting.

"6. Every practical method of restricting the extent to which the interference area of a station extends beyond its service area should be

employed. Specific measures include restriction of transmitter power to the level required for adequate service, suppression of harmonic emissions, synchronization of carriers where practicable ('offset carrier' in television broadcasting), and the employment of directional antennas. Where the cost of such measures is substantial, a suitable amortization period should be allowed.

"7. Services occupying regions of the spectrum not particularly adapted to their needs and capabilities should be transferred to other regions, in accordance with the dictates of full spectrum occupancy, and outmoded services deleted. Economic resistance to such shifts can be overcome by announcement of the impending change with a statement of the technical and economic advantages to be obtained, sufficiently in advance to permit old equipment to be amortized and to allow new equipment to be procured and installed. As knowledge of propagation and equipment improves and becomes stabilized, it should be possible to establish in advance the basis for such transfers over periods as long as 25 years, although a shorter period should suffice in most cases.

"8. Frequency assignments should be shared to the fullest practicable extent. Time sharing of frequency assignments is looked upon with disfavor by nearly all users of the spectrum and by many of its administrators, largely as a result of unfortunate experience. Geographical sharing is common in many services, including all forms of broadcasting, but is uncommon in others, as, for example, between military and civilian services. The difficulties of shared operation are mainly administrative. While not belittling the problems, we must recognize that the increasing congestion of the spectrum will eventually force greater reliance on shared operation."

These measures are typical of the action required in the program of dynamic spectrum conservation. Resistance can be expected from those required thereby to make changes in equipment and operating procedures. But if the changes can be shown to be technically sound and to have inherent ultimate benefit, they are in the public interest and are beneficial to private and government interests as well. When this benefit is recognized, and when the transfer is made in such a way as to avoid undue financial hardship, the resistance can be transformed to cooperative participation.

Sterile Plastic Petri Dishes.—Convenience of use-and-throw-away containers has been extended to serve the scientist and laboratory technician. New sterile plastic Petri dishes designed for one-time use are being placed on the market by the Chicago Apparatus Company. The dishes are used to grow microorganisms such as bacteria or tissue in hospital, research, and control laboratories. Expensive washing and sterilizing needed for glass Petri dishes can be eliminated.

The disposable plastic dishes are less than 9 cents each, depending on quantity, less than one-sixth the price of a glass Petri dish. It costs as much as 8 to 16 cents to get a glass dish ready for re-use, since it must be autoclaved, soaked, scraped, washed, rinsed, descaled, and baked.

The new Petri dishes are made of styrene plastic, are optically clear, and scratch free. They have a heat distortion point of 90 deg. C., are guaranteed sterile and pyrogen free, and are packaged to remain sterile for an indefinite shelf life. They meet the requirements for sterility set by *U. S. Pharmacopeia*. The plastic material contains no inhibiting agents and is inert to biological reagents.

Plastic plates containing pathogenic organisms may be destroyed by autoclaving or incinerating. The disposable plates make it unnecessary for laboratories to make a large investment in an extra supply of glass dishes for use during peak periods.

The plastic dishes are supplied 20 to a polyethylene bag which has a breather top to prevent condensation under humid conditions, and overpacked in a shipping carton containing 500 dishes.

Take Your House with You.—Like to move to a sunnier clime? Just pack up your house and take it with you! This may be possible in the not-so-distant future with buildings made of oil-based plastic "bricks." Architects at the University of Illinois have built a test structure—a dome 3 ft. high and 6 ft. in diameter, that can be folded and packed in a suitcase. It weighs only 10 lb! The dome consists of 112 triangular "bricks" made of translucent plastic, interconnected in such a way that they can be blown up like balloons singly or as a unit to form a rigid structure. It is expected that bricks for commercial use will be about three feet on a side and four inches thick. If one is punctured, others in the arch will support the building until a simple patch is applied. This may be the long-sought answer to the problem of building structures entirely in tension instead of compression. Most materials have more strength in tension, and therefore can be very thin and lightweight.

Pellet Drilling.—Oil company engineers have evolved pellet drilling, a new method of drilling oil wells. The technique, successfully laboratory-tested after 37 man-years of research, pulverizes rock by bombarding it with steel spheres at high velocity. While two nozzles utilize the drilling mud to circulate the pellets at the well bottom, a modified jet pump shoots the steel pills against the rock formation causing it to break up. Among the many advantages promised by the new technique are savings in drilling time and equipment wear-and-tear. The steel pellets can be replaced without hoisting the pipe out of the hole, and the drilling bit does not rotate.

NONLINEAR OSCILLATORS WITH CONSTANT TIME DELAY *

BY

W. J. CUNNINGHAM [1]

ABSTRACT

A particular family of electronic oscillators uses an amplifier with a feedback path consisting of a network that provides constant time delay for any signal. Oscillation may occur when the total phase shift around the feedback loop is a multiple of 2π radians and the net amplification is unity. For a system composed of ideal elements, oscillation may take place at an infinity of frequencies. Several systems of this type are discussed here. The amplifier is allowed to be ideal and linear, to saturate and be nonlinear, and to have simple low-pass properties. Somewhat different kinds of operation occur in these various cases. Mathematical analysis requires the use of nonlinear differential-difference equations, and a modification of the method of variation of parameters is used in their solution.

I. INTRODUCTION

One family of electronic oscillators makes use of an amplifier with an associated feedback path. Conditions for oscillation require that the total phase shift around the feedback loop be an integral multiple of 2π radians, and that the net amplification be unity. Usually the network providing feedback is chosen so that these conditions exist at but one frequency, and oscillation can occur only at this single frequency. An alternate possibility, however, is a feedback network which gives these conditions at several frequencies, so that the possibility of oscillation at more than a single frequency exists. In the following discussion is considered the case where feedback takes place through an ideal time delay network. This network delays any signal passing through it by a fixed time interval. It provides a phase shift that is a constant linear function of frequency at all frequencies. The resulting oscillator circuit is of interest because of the possibility of oscillation at many frequencies. The analysis of the system is of some interest because it requires consideration of differential-difference equations, rather than simpler pure differential equations. Furthermore, in order to be realistic, nonlinear effects must be considered. Certain kinds of oscillators having the possibility of oscillation at several frequencies have been analyzed in the past (**1–4**),[2] and there have been proposals to exploit their properties (**5**).

It is assumed throughout the following discussion that the elements of the system are somewhat idealized, and little is said about the cir-

* The work reported here was done under Contract Nonr-433(00) between Office of Naval Research and Yale University. The reproduction of this material in whole or in part is permitted for any purpose of the United States Government.

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[2] The boldface numbers in parentheses refer to the references appended to this paper.

cuitry involved. The design of amplifiers is well understood. Delay circuits can be made in several ways. These include circuits assembled with lumped elements, electrical transmission lines with distributed elements, acoustical transmission lines with appropriate transducers, a loop of magnetic tape running through recording and reproducing heads, and other systems as well. The delay circuit is assumed to provide constant time delay with no other change in the signal.

II. LINEAR IDEAL AMPLIFIER

The simplest oscillator, consisting of an amplifier and delay circuit, both ideal and linear, is shown in Fig. 1. This system is similar to cer-

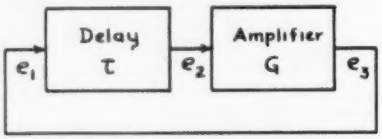

FIG. 1. Oscillator with linear ideal amplifier.

tain memory devices used in radars and digital computers (6). The properties of the two components can be described by relations involving instantaneous voltages at the points shown, $e_2(t) = e_1(t - \tau)$ and $e_3(t) = Ge_2(t)$. The delay time is τ and the amplification is G, both of which are real constants, although G may be either positive or negative. The equation for the system may be written

$$x(t) - Gx(t - \tau) = 0, \tag{1}$$

where variable $x(t)$ corresponds to voltage $e_1(t)$ at the input of the delay circuit.

While a mathematical analysis can be applied to this equation, a simple physical discussion is sufficient to describe the operation. If G is positive, there is no inversion of a voltage waveform by the amplifier, and oscillation may occur at any angular frequency ω for which the product $\omega\tau$ is an integral multiple of 2π radians. An infinity of harmonically related frequencies is allowed, including zero frequency. If G is negative, the amplifier inverts the waveform, and oscillation can occur only at those frequencies for which $\omega\tau$ is an odd multiple of π radians. Only odd harmonics of the lowest frequency can exist. In either case, if the magnitude of G is exactly unity, the amplitude of the signal is unchanged as it circulates around the loop and a steady state exists. If $|G| > 1$, the signal amplitude grows, while if $|G| < 1$ the amplitude decays, both at a constant rate. Evidently the waveform in the system can have an infinity of possible shapes, and the waveform which does exist can be known only if $x(t)$ is specified for the entire interval, $-\tau \leq t \leq 0$.

III. IDEAL LIMITING AMPLIFIER

Any amplifier that can be constructed from physical components will saturate for large signal amplitudes. This situation might be described by adding a limiter to the system of Fig. 1, giving that of Fig. 2. The simplest limiting action, in mathematical terms, can be expressed by the relation $e_3 = pe_4 + qe_4^3$ where p and q are constants. This relation gives the characteristic shown in Fig. 3. The equation for the system of Fig. 2 can be written

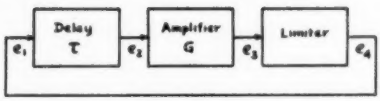

FIG. 2. Oscillator with limiting ideal amplifier.

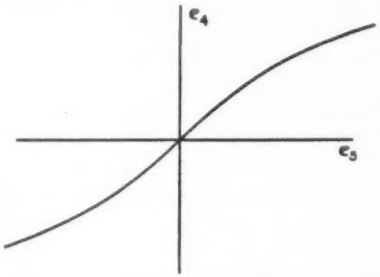

FIG. 3. Assumed characteristic of limiter.

$$x(t) - Cx(t - \tau) + gx^3(t) = 0, \tag{2}$$

where again $x(t)$ corresponds to the voltage at the input of the delay circuit, while $C = G/p$ and $g = q/p$.

Once more a simple physical discussion is sufficient to describe the operation of the system. If the nonlinear term gx^3 were missing, Eq. 2 would be the same as Eq. 1. Then, if $|C| > 1$, say $|C| = (1 + h)$ where $0 < h \ll 1$, any disturbance in the system would tend to increase in amplitude and the oscillator would be self starting. Quantity h is the fractional amount by which the amplification exceeds that just allowing steady-state oscillation. The primary effect of the nonlinear term is to give a throttling action and fix a steady-state amplitude. Since the limiter is the only nonlinear element, it provides the only distortion of waveform. In the steady state the voltage out of the limiter must be the same as that into the amplifier, that is, $|G|E = pE + qE^3$, where E is the voltage in question. Thus, either $E = 0$ or $E = \pm(h/g)^{\frac{1}{2}}$. If $|C| > 1$, the first case with $E = 0$ is unstable and represents growth from initial small disturbances, while the second case is stable.

By combining the conclusions reached in discussions relating to Figs. 1 and 2, the operation of the system of Fig. 2 can be summarized this way. If $C > +1$, possible waveforms include a positive or negative constant, or a rectangular wave jumping back and forth instantaneously

between positive and negative values. The only requirements on this wave are that it be periodic, with period τ or an integral submultiple of τ. If $C < -1$, possible waveforms include only a rectangular wave jumping between positive and negative values. This wave must be periodic with period 2τ, or an odd submultiple of 2τ, and be composed only of odd harmonics of the frequency $\omega = \pi/\tau$. The instantaneous value of either rectangular wave must be $\pm(h/g)^{\frac{1}{2}}$, and this is stable with respect to any small disturbances that may arise. The transition times for the wave depend upon initial conditions in the interval $-\tau \leq t \leq 0$. Any disturbance that may arise later to modify the instant of transition is maintained henceforth. Thus, the system displays a sort of neutral stability so far as disturbances of transition time are concerned.

The foregoing conclusions can be obtained in more detail by mathematical analysis. This analysis is complicated because of the possibility of simultaneous oscillation at an infinity of frequencies. One example that has been worked out is that for the system of Fig. 2 with $C < -1$ under the assumption that two frequencies are present at the same time. While the actual oscillation must include an infinity of frequencies, the case of two frequencies is about as complicated as can be handled with much ease. A stable solution can be shown to exist in the form

$$x/U = 1.07\cos(\omega t + \theta_1) + 0.32\cos(3\omega t + \theta_2), \tag{3}$$

where $U = (4h/3g)^{\frac{1}{2}}$. It is necessary that $(3\theta_1 - \theta_2) = \pi$ and that $\omega\tau$ be an odd multiple of π. If Eq. 3 is plotted, it is found to approximate closely a square wave of amplitude $(h/g)^{\frac{1}{2}}$, as is to be expected. The analysis leading to Eq. 3 is rather long and is not given here. The methods used are similar to those developed in the discussion which follows below.

IV. LOW-PASS LINEAR AMPLIFIER

In the preceding section it was argued that any practical amplifier becomes nonlinear for large signals. In addition, any practical amplifier is inherently a low-pass device and its amplification is reduced at higher frequencies. This effect might be approximated by adding a simple

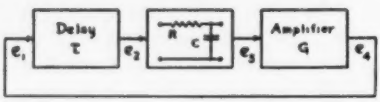

FIG. 4. Oscillator with low-pass linear amplifier.

R-C network as shown in Fig. 4. In this system, the amplifier is again assumed to be linear, although later it is allowed to be nonlinear once more. The R-C network has the property $e_2 = RC\dot{e}_3 + e_3$ where the

dot signifies differentiation with respect to time. The equation for the system of Fig. 4 then may be written

$$\dot{x}(t) + ax(t) - bx(t - \tau) = 0, \tag{4}$$

where $x(t)$ again corresponds to the voltage at the input of the delay circuit. The coefficients are $a = 1/RC$ and $b = G/RC$ where R is the resistance and C is the capacitance of the added network.

The effect of the R-C network is to introduce phase shift and attenuation in the feedback loop. Both these are functions of frequency. One result is that, with proper choice of amplification, oscillation may occur only at the lowest of the possible frequencies, rather than at an infinity of frequencies. This system is now discussed in more detail than has been used previously (7).

The differential-difference equation, Eq. 4, has a solution of the form

$$x = A \exp(mt), \tag{5}$$

where A is an arbitrary constant and m is a complex quantity, $m = (\delta + j\omega)$, that must satisfy the relation

$$m + a = b \exp(- m\tau). \tag{6}$$

This equation may be separated to give

$$real: \delta + a - b \exp(- \delta\tau) \cos\omega\tau = 0 \tag{7}$$

$$imaginary: \omega + b \exp(- \delta\tau) \sin\omega\tau = 0. \tag{8}$$

It is possible for m to be a real quantity, in which case ω is zero and m must satisfy Eq. 6 directly. A nonoscillatory solution for Eq. 4 then exists. Allowed values of m can be found by a graphical construction, in which intersections of curves representing the quantities $(m + a)\tau$ and $b\tau \exp(- m\tau)$ plotted as a function of $m\tau$ are found. A variety of possibilities may occur and the situation is summarized in Fig. 5. While the value of coefficient a must be positive for positive circuit elements, it is allowed to become negative here for generality. If $b\tau > 0$, a single real value of m exists although it may be either positive or negative. If $b\tau < - \exp(- 1 - a\tau)$ no real value of m exists. If $- \exp(- 1 - a\tau) < b\tau < 0$, two real values of m exist. If m has a positive real value, the solution grows indefinitely with time and the system may be described as unstable. There is obviously a large range of combinations of $a\tau$ and $b\tau$ which lead to instability of this sort.

If oscillatory solutions do exist, $\omega \neq 0$, and both Eqs. 7 and 8 must be considered. Because of the large number of parameters, it is simplest to discuss only the case of $\delta = 0$, corresponding to a steady sinusoidal

oscillation. If $\delta = 0$, then

$$a = -\omega/\tan\omega\tau \tag{9}$$

$$b = -\omega/\sin\omega\tau = a/\cos\omega\tau. \tag{10}$$

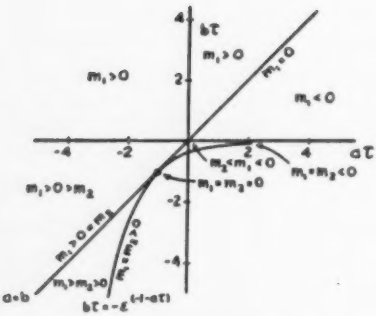

FIG. 5. Relations between real roots of Eq. 6.

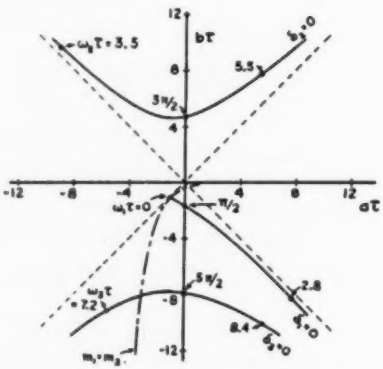

FIG. 6. Contours for pure imaginary roots of Eq. 6.

Because of the periodicity of the trigonometric functions, an infinity of values for ω is again possible. Contours are shown in Fig. 6 for the first three sets of combinations of $a\tau$ and $b\tau$ leading to sustained steady-state oscillations. Frequencies for certain points along these contours are indicated. In general, if $a\tau$ is held constant and $|b\tau|$ is increased beyond the value making $\delta = 0$, the resulting value of δ is positive. This corresponds to a solution with a growing oscillation which is unstable. Thus, unstable oscillating solutions exist for values of $a\tau$ and $b\tau$ above the contours for $\delta = 0$ in the first and second quadrants of Fig. 6, and below these contours in the third and fourth quadrants.

The general form of the solution for Eq. 4 becomes

$$x = B_1 \exp(m_1 t) + B_2 \exp(m_2 t) + \sum_{k=1}^{\infty} A_k \exp(\delta_k t) \cos(\omega_k t + \theta_k), \tag{11}$$

where B_1, B_2, A_k, and θ_k are arbitrary constants, and m_1, m_2, δ_k, and ω_k are found from Eqs. 6–8. If $m_1 = m_2$ the first two terms of Eq. 11 become $(B_1 + B_2 t)\exp(m_1 t)$. Again, in order to evaluate the infinity of arbitrary constants, $x(t)$ must be specified for the interval $-\tau \leq t \leq 0$.

V. LOW-PASS LIMITING AMPLIFIER

With both the saturating action and the low-pass effect of a practical amplifier considered, the system becomes that shown in Fig. 7. This

system is a combination of those of Figs. 2 and 4, and it may be described by the equation

$$\dot{x}(t) + ax(t) - aCx(t - \tau) + g[ax^3(t) + 3x^2(t)\dot{x}(t)] = 0, \quad (12)$$

where again $x(t)$ corresponds to the voltage at the input of the delay circuit, while $a = 1/RC$, $C = G/p$, and $g = q/p$. Probably the kind of operation of most interest is that where oscillation takes place at only a single frequency and is self starting so that it will build up from an initial small disturbance.

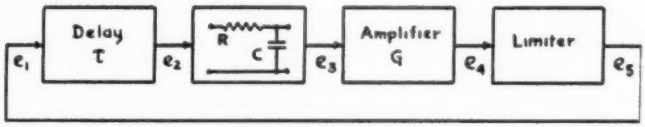

FIG. 7. Oscillator with low-pass limiting amplifier.

Nonlinear differential equations with oscillating solutions are often studied by the method of variation of parameters (8). A modification of this same technique can be used with the nonlinear differential-difference equation, Eq. 12. This process is useful only so long as any change in amplitude or relative phase of oscillation takes place only slowly, requiring many cycles for a significant change to occur. As the first step, a generating solution is found as

$$x = A\cos(\omega t + \theta) = A\cos\phi, \quad (13)$$

where $\phi = (\omega t + \theta)$ is a general angle variable. This solution applies exactly to the equation in question provided certain terms, including the nonlinear terms, are omitted. The effect of these terms is then accounted for by allowing amplitude A and phase angle θ to vary with time. Usually only average values for $\dot{A}$ and $\dot{\theta}$, with the average taken over a cycle of the oscillation, can be found. It is necessary that $\dot{A}T/A \ll 1$ and $\dot{\theta} \ll \omega$, where T is the period.

If the generating solution of Eq. 13 is to apply exactly to Eq. 12, the nonlinear term with coefficient g must be disregarded. Furthermore, if coefficient a is specified, coefficient aC must have a predetermined value, say aC_0. This aC_0 is analogous to b in Eq. 4, and the necessary relation is given in Fig. 6 on a contour for $\delta = 0$. Probably the only mode of oscillation of any importance is that leading to the lowest possible frequency, ω_1, so that the relation between a and b (corresponding to aC_0) is given by the contour for $\delta_1 = 0$. Any mode of oscillation other than the lowest frequency always allows some other unstable solution to exist, as can be seen from Figs. 5 and 6.

In a self-starting oscillator, the magnitude of C must exceed C_0 by a

small amount, $C = C_0(1 + h)$ where $0 < h \ll 1$. Equation 12 can then be written

$$\ddot{x}(t) + ax(t) - aC_0x(t - \tau) = aC_0hx(t - \tau) - g[ax^3(t) + 3x^2(t)\dot{x}(t)]. \quad (14)$$

The generating solution Eq. 13 applies exactly to Eq. 14 if the terms in g and h are disregarded. The effect of these terms can be accounted for by letting A and θ vary with time. Then

$$\dot{x}(t) = -\omega A \sin\phi + \dot{A}\cos\phi - \dot{\theta}A\sin\phi. \quad (15)$$

Furthermore, approximately

$$x(t - \tau) = (A - \dot{A}\tau)\cos[\omega(t - \tau) + \theta - \dot{\theta}\tau], \quad (16)$$

where $\dot{A}$ and $\dot{\theta}$ are averaged over a cycle and are assumed small. With $\delta = 0$ and $b = aC_0$, Eqs. 7 and 8 become

$$\cos\omega\tau = 1/C_0 \quad (17)$$

$$\sin\omega\tau = -\omega/aC_0. \quad (18)$$

These equations can be used in Eq. 16 after it has been expanded to give

$$x(t - \tau) = (A - \dot{A}\tau)(1/C_0)[\cos\phi - (\omega/a)\sin\phi] + \dot{\theta}A\tau(1/C_0)[\sin\phi + (\omega/a)\cos\phi]. \quad (19)$$

Similarly,

$$hx(t - \tau) = (hA/C_0)[\cos\phi - (\omega/a)\sin\phi] \quad (20)$$

$$x^3(t) = (A^3/4)(3\cos\phi + \cos3\phi) \quad (21)$$

$$x^2(t)\dot{x}(t) = -(A^3\omega/4)(\sin\phi + \sin3\phi), \quad (22)$$

where only first-order variations have been used in writing all these equations. Equations 15, 19–22 can be inserted in Eq. 14. Certain terms cancel immediately because Eq. 13 satisfies Eq. 14 with terms in g and h omitted. Additional terms will involve either $\cos\phi$ or $\sin\phi$, and if the equation is to hold at all instants, these terms must separately satisfy the equation. Finally, there are terms in $\cos3\phi$ or $\sin3\phi$ which cannot satisfy the equation. These represent an error in the solution, and are considered later in a discussion of distortion.

The relations coming from terms in $\cos\phi$ and $\sin\phi$ are

$$\cos\phi: \dot{A}(1 + a\tau) - \dot{\theta}A\omega\tau = ahA - 3agA^3/4 \quad (23)$$

$$\sin\phi: -\dot{A}\omega\tau - \dot{\theta}A(1 + a\tau) = -\omega hA + 3\omega gA^3/4. \quad (24)$$

These simultaneous equations can be solved algebraically for $\dot{A}$, giving

$$\dot{A} = (h - 3gA^2/4)\mu A, \tag{25}$$

where

$$\mu = \frac{a(1 + a\tau) + \omega^2\tau}{(1 + a\tau)^2 + (\omega\tau)^2}. \tag{26}$$

With $h > 0$, there are two equilibrium values for A for which $\dot{A} = 0$. Unstable equilibrium exists if $A = 0$, while stable equilibrium exists if $A = U = (4h/3g)^{\frac{1}{2}}$. The way amplitude changes with time is shown in Fig. 8.

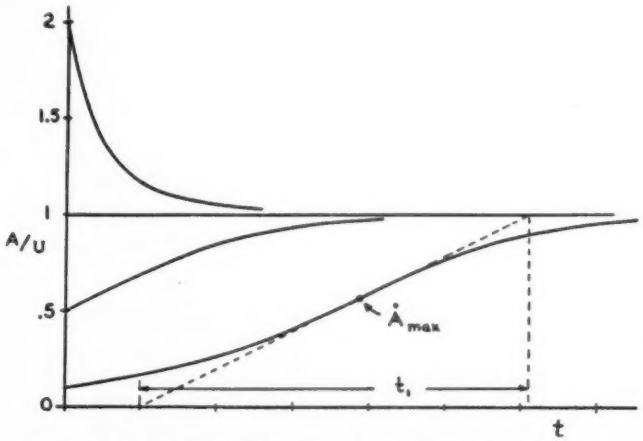

FIG. 8. Variation of amplitude with time in oscillator of Fig. 7. Several different initial amplitudes are shown.

The maximum value of $\dot{A}$, as A increases from an initial small value, exists if $A = U/3^{\frac{1}{2}}$ and is $\dot{A}_{max} = 2h\mu U/3^{\frac{1}{2}}$. A time t_1 can be defined as shown in Fig. 8 as the interval required for A to change by the amount U at the constant rate $\dot{A}_{max}$. This time is given by the equation

$$t_1 = U/\dot{A}_{max} = 3^{\frac{1}{2}}/2h\mu. \tag{27}$$

According to the assumptions in the analysis, many cycles of the oscillation must occur in this interval. Thus, it is necessary that $t_1/T \gg 1$ or that $h \ll 3^{\frac{1}{2}}\omega/4\pi\mu$. A little number work shows that the product $\mu\tau$ has the value unity if $\omega\tau = 0$ or $\omega\tau = \pi$, and is only slightly less than unity for intermediate values of $\omega\tau$, being about $\mu\tau = 0.7$ if $\omega\tau = \pi/2$. Thus, if $\omega\tau$ is small, as may be the case for the lowest frequency of oscillation, it is necessary that h be quite a small number.

When Eqs. 23 and 24 are solved for θ and the steady-state amplitude

$A = U$ is inserted, it is found that $\theta = 0$. The limiter does not modify the frequency of oscillation in the steady state, at least to the first order of approximation.

If the oscillator is operating in the steady state, the limiter introduces distortion and the waveform is nonsinusoidal. A kind of perturbation analysis can be used to estimate this distortion. The solution for Eq. 14 might be written

$$x = x_1 + x_3 = A_1 \cos\phi_1 + A_3 \cos(3\phi_1 + \theta_3). \tag{28}$$

The first term is merely the generating solution of Eq. 13 with $A_1 = U$ and θ_1 set arbitrarily to zero so that $\phi_1 = \omega_1 t$. The limiter introduces primarily a third-harmonic component, the second term of Eq. 28. Amplitude A_3 and phase angle θ_3 must be determined, while $3\phi_1 = 3\omega_1 t$. In the previous solution for the equation, x_1 has been found so that it satisfies those terms of Eq. 14 having the fundamental frequency. Thus, the added term, x_3, must satisfy the equation

$$\dot{x}_3(t) + ax_3(t) - aC_0 x_3(t - \tau) = -g(A_1^3/4)(a\cos 3\phi_1 - 3\omega_1 \sin 3\phi_1). \tag{29}$$

The terms in $\cos 3\phi_1$ and $\sin 3\phi_1$ on the right side of Eq. 29 are those neglected in getting Eqs. 23 and 24 from Eq. 14.

If the value of x_3 from Eq. 28 is used in Eq. 29, and terms in $\cos 3\phi_1$ and $\sin 3\phi_1$ separated, the result is

$$cos3\phi_1 : A_3(u\cos\theta_3 - v\sin\theta_3) = -agA_1^3/4 \tag{30}$$

$$sin3\phi_1 : A_3(-v\cos\theta_3 - u\sin\theta_3) = 3\omega_1 gA_1^3/4. \tag{31}$$

Here, the abbreviations have been made

$$u = a(1 - C_0 \cos 3\omega_1\tau) = 4a(1 - 1/C_0^2) \tag{32}$$

$$v = 3\omega_1 + aC_0 \sin 3\omega_1\tau = 4\omega_1^3/a^2C_0^2, \tag{33}$$

where Eqs. 17 and 18 have been used to evaluate $\cos 3\omega_1\tau$ and $\sin 3\omega_1\tau$.

Equations 17, 18, 30–33 can be combined to give

$$\tan\theta_3 = -2\tan\omega_1\tau/(1 + 3\tan^2\omega_1\tau). \tag{34}$$

Thus, phase angle θ_3 is zero if $\omega_1\tau$ is any integral multiple of $\pi/2$. Angle θ_3 is maximum, $\theta_3 = \pm\pi/6$ if $\omega_1\tau = \mp\pi/6, \pm 5\pi/6, \ldots$. In a similar manner, A_3 can be found as

$$A_3 = -(hA_1/12)\left|\frac{(1 + 9\tan^2\omega_1\tau)^{\frac{1}{2}}}{\sin\omega_1\tau\tan\omega_1\tau}\right|. \tag{35}$$

Ratio A_3/A_1 is a minimum, $A_3/A_1 = -h/4$, if $\omega_1\tau = \pi/2, 3\pi/2, \ldots$. This condition also makes $\theta_3 = 0$, so that the waveform then differs least from a sinusoid. Ratio A_3/A_1 is infinite according to Eq. 35 if $\omega_1\tau = 0, \pi, \ldots$ but the analysis is not valid for such large distortion.

TABLE I.—*Numerical Examples.*

$\omega\tau$	$\pi/2$	$5\pi/6$	radian
τ	2	2	sec
T	8.00	4.80	sec
g	8.4×10^{-5}	8.4×10^{-5}	volt^{-2}
h	0.2	0.2	
a	0	2.27	sec^{-1}
$b = aC_0$	-0.785	-2.62	sec^{-1}
$A_1 = U$	56.3	56.3	volt
A_3/A_1	0.05	0.115	
θ_3	0	$\pi/6$	radian
t_1	36.6	30.4	sec
t_1/T	4.57	6.33	

One final comment regarding the stability of the system should be made. It was observed previously in connection with the definition of growth time t_1 that if $\omega\tau$ is very small, even a small value of h is enough to lead to rapid growth of oscillation. It is possible to show further that with $\omega\tau$ near zero (which requires $a\tau$ to be negative, from Fig. 6), too large a value of h will make the nonlinear system unstable so that x increases without bound. In order to avoid this instability, the requirement is that $h < (3/2)(\omega\tau)^2/[1 - 2(\omega\tau)^2]$. The reason for this instability is evident from Fig. 6. If the instantaneous value of x becomes large, the limiter reduces the effective gain of the amplifier, thereby reducing the effective magnitude of coefficient b. For combinations of a and b that lead to small $\omega\tau$, a sufficient reduction in b throws the system into instability.

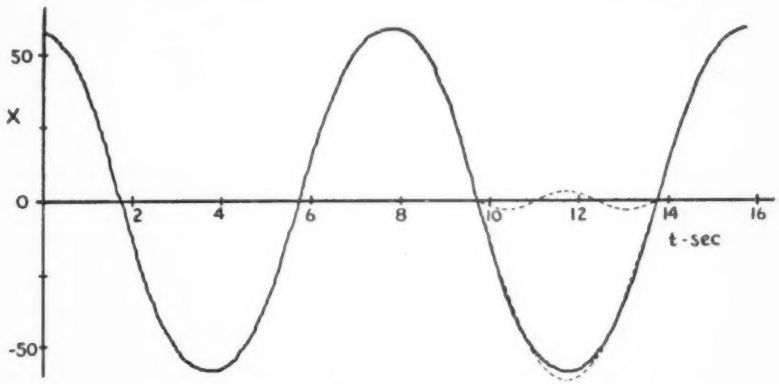

FIG. 9. Steady-state oscillation for system of Fig. 7, $\omega\tau = \pi/2$.

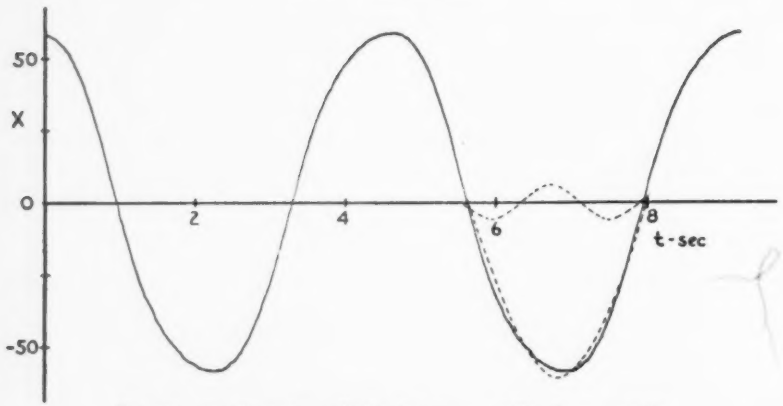

FIG. 10. Steady-state oscillation for system of Fig. 7, $\omega\tau = 5\pi/6$.

The system of Fig. 7 has been studied using an electronic analog computer. The delay circuit was assembled from the computer elements (9). The limiting action was provided with a servo-driven nonlinear potentiometer. Numerical data calculated from the results of the preceding analysis are given in Table I for two specific cases. Steady-state oscillations for these cases are shown in Figs. 9 and 10 as plotted directly by the computer. The computer curves agree well with the calculated data. On one half cycle of each curve are plotted the predicted fundamental and third-harmonic components. In Fig. 11 is shown the growth of oscillation for the case of $\omega\tau = \pi/2$. The observed growth time t_1 is about 15 per cent longer than the predicted value.

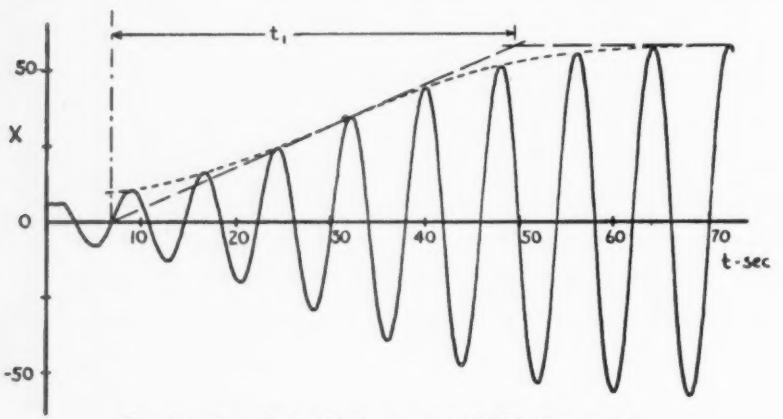

FIG. 11. Growth of oscillation for system of Fig. 7, $\omega\tau = \pi/2$.

In conclusion, the oscillator of Fig. 7 can be compared with the classic van der Pol oscillator (10), described by the standard equation

$$\ddot{x} - \epsilon(1 - x^2)\dot{x} + x = 0. \tag{36}$$

This pure differential equation applies to an electronic oscillator composed of a parallel L-C circuit connected in parallel with a nonlinear voltage-controlled negative resistance. The nature of the resulting oscillation depends upon parameter ϵ. If ϵ is small, oscillation is almost sinusoidal at a frequency independent of ϵ to a first approximation. Third-harmonic distortion exists, the relative amount being proportional to ϵ. The waveform is asymmetrical, with the flattened top sloping downward in the direction of increasing time, just opposite from Fig. 10. The rate of growth of amplitude depends upon ϵ but the steady-state amplitude is a constant two units.

The system of Fig. 7 requires description by the differential-difference equation, Eq. 14. Parameter h is somewhat analogous to ϵ of Eq. 36, but operation is now more complicated. If h is small, oscillation is almost sinusoidal at a frequency independent of h. Third-harmonic distortion exists, in magnitude proportional to h. The relative distortion also depends upon $\omega\tau$ in a complex manner, and the resulting waveform may be symmetrical or may have a flattened top skewed either way. The rate of growth of amplitude depends upon h, while the steady-state amplitude varies as $h^{\frac{1}{2}}$.

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High Q Stalo Cavity.—A new, commercially practical high Q Cavity, the VA–1280 Stalo Cavity, featuring high stability without electronic components, has been announced by Varian Associates, manufacturers of klystrons, n-m-r spectrometers, electromagnets and other electronic equipment. It provides a very high degree of short time frequency stability, according to the manufacturer's statement.

Elimination of all electronic components is said to afford stabilization which is independent of the frequency of oscillator fluctuations and external disturbances and to assure greater reliability and longer life.

The new VA–1280, together with Varian Models VA–1281 and 1282, comprise a line of high Q Cavities offering stabilization factors from 15 to 160, and covering a wide range of important applications such as stabilization of signal sources in high power klystron transmitters, airborne uses in conjunction with receiver local oscillators and laboratory testing.

According to the manufacturer's announcement, the stability of the VA–1280 when used with Varian's new highly stable reflex klystron oscillator, is comparable to that of many crystal controlled oscillators.

Yale Develops Drum Handling Clamp for Easy Horizontal Placement.—The Yale & Towne Manufacturing Company has announced the development of a new rotating drum handling attachment of 200 pound capacity which can serve a number of drum handling assignments and is particularly effective where quick horizontal placement or stacking is a materials handling requirement.

The attachment's distinctive ability lies in the design of the rubber coated clamp arms. One arm is articulating and shaped with two concavities which fit the shape of a drum. The other is flat surfaced and tapered slightly so that upon release of clamping pressure the drums will roll into position.

Yale's new attachment rotates through a 90-deg. arc to permit picking up drums in the vertical position and stacking them horizontally at a height dictated by the capacities of the Yale truck on which it is mounted. The new clamp can handle two drums in this manner.

Used to pick up, transport and stack drums vertically, the attachment can handle four drums at one time. Clamping range of the 42-in. long arms is from $17\frac{3}{8}$ in. to $71\frac{3}{8}$ in.

Nickel Protects Aircraft Propellor Blades.—A new coating process developed by Hamilton Standard superimposes nickel plating on either solid aluminum or hollow steel blades. The process "armor coats" aircraft propellors with a thin layer of nickel that has proven an effective method of protection against damage from stones, debris, or water spray.

The process first proved its success in protecting the aluminum blades of P5M Marlin flying-boats from the eroding effect of water spray. Adapted to hollow steel blades by changes in the bonding agent, the nickel plating substantially reduced damage caused by stones and debris on the steel blades of R4Q–1 and P2V–7 type aircraft.

MECHANICAL BEHAVIOR OF FIBERS

BY

F. AKUTOWICZ [1]

SUMMARY

This paper is concerned with the phenomenology of visco-elasticity approached by means of differential equations. Three results are given which are new and not generally known to workers in the field. 1. The geometrical meaning of 1st order differential equations is given in the context of mechanical behavior of fibers. This frees the researcher of an obligation to interpret his equations in terms of springs and dashpots. 2. Operational methods are given for determining if any 1st order differential equation (linear or not) can provide an adequate description for a particular fiber. 3. For cases where a differential equation is satisfactory an operational method is given for constructing it directly in the laboratory rather than attempting to fit experimental trajectories to solutions of assumed differential equations.

A PROBLEM IN PHENOMENOLOGY

When a material exhibits elastic, plastic and fluid properties simultaneously (as most textile fibers do) its specification in succinct form becomes an intriguing exercise in applied mathematics and physical intuition. The great variety of behavior possible and the almost complete absence of a technically useful *description* of all that is possible has provided the stimulus for a great deal of research into this problem (1).[2] The problem of subsequent interpretation of mechanical behavior in terms of molecular theories is quite different and will not be considered here.

A GRAPHICAL SOLUTION

At present, the most satisfactory and trustworthy description is *pictorial*, for example (2)—a line diagram is made of the force response to different types of extension as determined by a suitable testing machine. This method of description could be used in subsequent stress analysis if the loading pattern exerted by the testing machine bears some resemblence to the loads subsequently encountered by the material in use. But if not, then a second diagram must be made to cover the extended range of load patterns. And, in general, if the material is to be subjected to many different types of load a series of pictures will be needed for an adequate description. This is the situation with tire cord, for example, which is commonly subjected to steady forces, forces containing a few low frequencies, and impact forces containing many high frequencies. This is an engineer's solution to the problem of description—a representation of the behavior in functional form. To

[1] American Viscose Corporation, Marcus Hook, Pa.

[2] The boldface numbers in parentheses refer to the references appended to this paper.

be sure, the function is given graphically on several sheets of graph paper but still a *function*.

SOLUTION BY DIFFERENTIAL EQUATIONS

Another method of specifying mechanical behavior of fibers is in terms of differential equations relating force, elongation, and their time derivatives. Such an equation is

$$\alpha \frac{dF}{dt} + \beta \frac{dD}{dt} + \gamma = 0, \tag{1}$$

where α, β and γ are constants, F is force, D is elongation and t is time. This is an underdetermined equation which can be made determinate only by fixing either $F(t)$ or $D(t)$. Let $D = kt$. Then the solution of Eq. 1 becomes

$$F + \frac{1}{\alpha}\left(\beta + \frac{\gamma}{k}\right) D = 0.$$

This is shown in Fig. 1 for different values of k. Such an equation de-

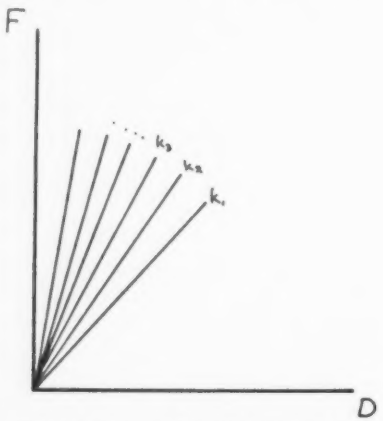

FIG. 1. Some possible solutions to Eq. 1.

scribes a rate sensitive material since k is the rate of extension of the specimen. Equation 1 by itself thus represents an infinity of Force-Elongation diagrams.

The capabilities of an underdetermined differential equation for describing variegated behavior have been appreciated for a long time. And as a result many mathematical models have been produced intending to describe visco-elastic behavior. A summary of some of the more successful models is given in (3).

SOLUTION BY INTEGRAL EQUATIONS

Even a differential equation, however, has limitations in the types of behavior it can describe, and most researchers into mechanical behavior have drifted away from the description by means of differential equations to that by integral equations. An integral equation represents an infinity of differential equations and hence is even more flexible as a describer of mechanical behavior. An example of an integral equation is

$$D(t) = \int_0^t K(t, s)F(s)ds \tag{2}$$

in which K is a known kernel function and either D or F is known. A solution to an integral equation has the property that it depends in an explicit way on the entire prior history of the material being worked. On the other hand the solution of a differential equation is defined in part by the local properties of the equation and in part by its own very recent history, and is largely independent of most of its prior history. However, if an inclusive description is desired, an integral equation presents serious difficulties in its construction in the laboratory. Not so with a differential equation.

DISCUSSION OF RESPECTIVE MERITS AND STRATEGY ADOPTED

For descriptive purposes a differential equation has the following strategic advantages over an integral equation:

1. Differential equations are more *anschaulich* than integral equations. That is, they give an intuitively clearer description of what is happening.
2. Differential equations are much easier to construct in the laboratory than integral equations.
3. It is much easier to get numerical solutions to differential equations than to integral equations.

The disadvantage of differential equations is that the insight they give might not be genuine. They have inadequate mathematical generality, and in many cases fail to describe the behavior actually exhibited by visco-plasto-elastic fibers. That is, they are phenomenologically inadequate.

But the possible advantages are so great that for any particular species of fiber it is worth checking to see whether a differential equation *is* adequate. The means toward this end form the subject matter of this paper. Specifically, this paper contains:

1. A geometrical interpretation of what first order differential equations have to say about force and elongation. This frees the researcher from the necessity of a physical interpretation of his equation á la springs and dashpots or other paraphernalia.

2. Methods of constructing differential equations in the laboratory.
3. Methods of determining whether a differential equation (*any* differential equation) is an adequate representation of the fiber behavior being actually exhibited.

A LOOK AT THE PROBLEM FROM FIRST PRINCIPLES

Figure 2 shows a sight familiar to anyone who has tested textiles or plastics. In this figure a single stress-strain trajectory is viewed from

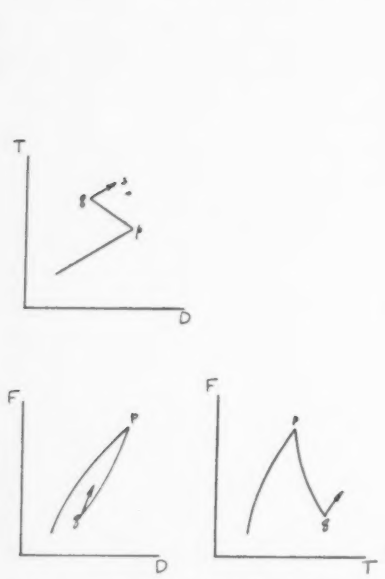

FIG. 2. The three dimensional nature of stress-strain diagrams.

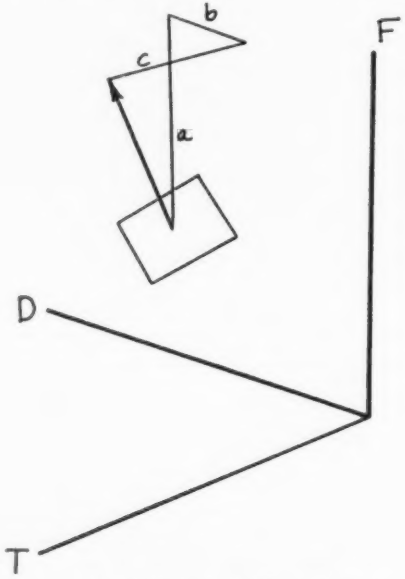

FIG. 3. Local orientation of the surface containing the stress-strain trajectory.

three perpendicular directions. F is some measure of force, D of deformation of the fiber being studied and T is time. For elastic bodies there is no dissipation of energy, as there is in Fig. 2, and the slopes leading into and out of points p and q are equal as seen in the F-D plane. And the trajectory descending from p coincides with that ascending to p. The force-deformation diagram is a single line (which might be curved) starting at the origin. This line could be regarded as the trace on the F-D plane of a cylindrical surface whose generators are parallel to the T axis. The force-deformation curve in F-D-T space is then a zig-zag line lying on the cylindrical surface. The trace of this line on the F-D plane is an experimental determination of what can properly

be called the stress-strain law for the material. For Hookean materials the cylindrical surface degenerates into a plane containing the T axis.

Definition. A simple fiber is said to be elastic or insensitive to rates if any trajectory lies on a cylinder perpendicular to the F-D plane.

But a rate sensitive fiber's trajectory is *off* any such single valued surface. Let us consider the events taking place in the neighborhood of point p, Fig. 2. Instead of lying entirely in a surface, the trajectory now lies in a surface only *locally*. Specifically, in the vicinity of point p, let the surface be a small postage-stamp-shaped piece of a plane oriented as shown in Fig. 3. The orientation is conveniently specified in terms of the components of the perpendicular vector shown growing out of the rectangle. If the component c were zero the postage stamp would be perpendicular to the F-D plane. As it is it slopes downward for increasing T. We can now show that trajectories constrained to lie in the postage stamp in the neighborhood of p can negotiate the acute angle seen in the F-D plane. The equation of the postage stamp plane is

$$aF + bD + cT = K, \quad \text{(a constant)} \tag{3}$$

in which $a > 0$, $b < 0$, and $c > 0$.

The equation, as seen in the D-T plane, of the trajectory going into point p is

$$b_1D + c_1T = K_1, \quad \text{(another constant)} \tag{4}$$

in which $b_1 < 0$ and $c_1 > 0$.

Departing from p, the equation is

$$b_2D + c_2T = K_2, \quad \text{(another constant)} \tag{5}$$

in which $b_2 > 0$ and $c_2 > 0$.

Let us take the loading and unloading rates equal numerically. Then $b_2 = -b_1$ and $c_2 = c_1$. Eliminating T between Eqs. 3 and 4 produces

$$(c_1a)F + (c_1b - cb_1)D = \text{constant}, \tag{6}$$

and between Eqs. 3 and 5 produces

$$(c_2a)F + (c_2b - cb_2)D = \text{constant}. \tag{7}$$

dF/dD computed from Eqs. 6 and 7, respectively, are the slopes as seen on the F-D plane going into and out of the point p.

$$dF/dD)_{\text{in}} = -\frac{b}{a} + \frac{cb_1}{c_1a}$$

$$dF/dD)_{\text{out}} = -\frac{b}{a} + \frac{cb_2}{c_2a} = -\frac{b}{a} - \frac{cb_1}{c_1a}.$$

The quantity $-b/a$ is positive and the quantity c_1/b_1 is negative (being the rate of extension of the specimen). $dF/dD)_{in}$ is therefore smaller than $dF/dD)_{out}$ by the quantity $2cb_1/c_1a$, Fig. 4. That is, the slope leaving p is steeper than the slope entering. The constants a, b, c are constant only locally—in actuality they are functions of F and D. Specifically, c is $c(F, D)$. In the neighborhood of q, c must be negative to account for the steeper slope leaving q compared to entering. Thus in going from p to q the sign of c changes. It is reasonable to expect

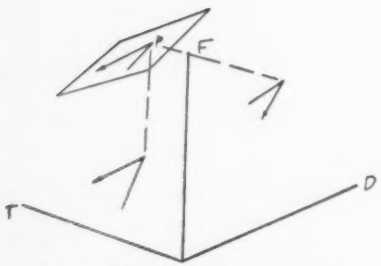

FIG. 4. Negotiating the corner at p.

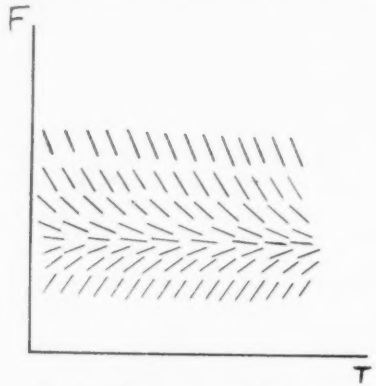

FIG. 5. Isoclines exposed by a cut D = constant.

that there is an intermediate point where $c = 0$. At this point the postage stamp is perpendicular to the F-D plane and locally no dissipation takes place. This is a point on Halsey's spring line. The fact that a, b, and c are not absolute constants requires that F, D and T be limited to small excursions during which time a, b, and c remain stable. This limitation can be expressed symbolically by writing differentials instead of gross variables in Eq. 3, as follows,

$$a(F, D)dF + b(F, D)dD + c(F, D)dT = 0. \tag{8}$$

The constant on the right can be taken as zero because the point (F, D, T) is taken as a roving origin from which dF, dD, dT are short excursions. a, b, and c cannot depend on T because that would imply that the fiber is changing spontaneously in time, and if we require the fiber to be sufficiently inert for technological usefulness, T cannot enter a, b, c explicitly. This means that the orientation of the small postage stamp is identical for all points on lines parallel to the T axis. They can be visualized as so many fish scales which fill the working volume of F-D-T space. Or they can be regarded as three dimensional isoclines all pointing toward the spring surface (the spring line must be generalized to

that). Thus a cut through the working volume of F-D-T space would expose a two dimensional field of isoclines all tending toward the trace of the spring surface, Fig. 5. In this figure the cut is made by a D = constant plane.

Most of the equations used by previous researchers in visco elasticity are special cases of Eq. 8. For example, Maxwell's and Eyring's are such equations.

Maxwell: $\dot{F} - \alpha\dot{D} + \beta F = 0$, α,β are constants.

Eyring: $\dot{F} - \alpha\dot{D} + \beta \sinh[\gamma(F - \delta D)] = 0$, $\alpha,\beta,\gamma,\delta$ are constants.

Eq. 8: $a(F, D)\dot{F} + b(F, D)\dot{D} + c(F, D) = 0$.

To summarize, a differential equation like (8) is capable of describing the main facts of visco elasticity:

1. The equation $c(F, D) = 0$ gives the equation for the spring line, Fig. 6.

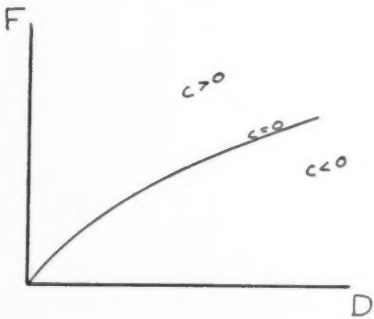

FIG. 6. F-D space is divided by the spring line.

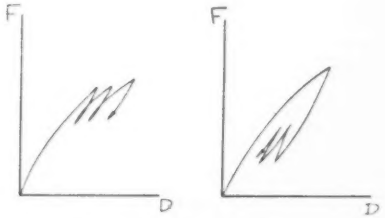

FIG. 7. Deformation can increase or decrease under cyclic loading.

2. Subjecting a fiber to cyclic loads above the spring line results in a rapidly growing specimen and below the spring line a shortening specimen, Fig. 7.

3. Slopes are steeper (as seen on the F-D plane) for faster rates of loading and unloading up to a maximum slope (corresponding to the rate $c_i/b_i \rightarrow \pm\ \infty$ in the expression for dF/dD given previously).

4. From a point like p, Fig. 2, the force will relax down to the spring line if D is held constant. And from a point like q the force will increase up to the spring line.

5. If F is held constant, D will increase from a point like p, Fig. 1, and decrease from q.

GENERALIZATION OF EQ. 8

Equation 8 is a special case of a wider class of equations. Although Eq. 8 contains non-linear combinations of F and D, it contains only linear combinations of $\dot{F}$ and $\dot{D}$, and this fact distinguishes it from the general case. In the general case the variables F, D, $\dot{F}$, and $\dot{D}$ are combined in a functional form which is not specified in advance. Call it $M(F, D, \dot{F}, \dot{D}) = 0$. The theory of equations like $M(F, D, \dot{F}, \dot{D}) = 0$ is quite old and is described in some detail in (4), Chapter 2, Section 5. For rheological application, the significant feature of the general theory is that types of behavior not amenable to description by Eq. 8 are likewise not described by a more complicated 1st order differential equation.

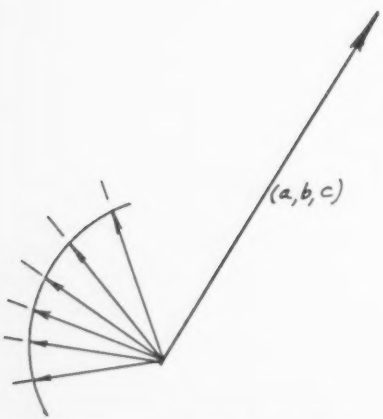

FIG. 8. The vector (a,b,c) is perpendicular to the plane of the trajectory fan.

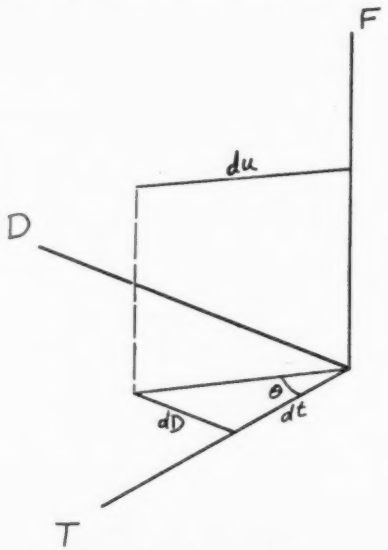

FIG. 9. The coordinates of the space containing the trajectory fans.

To appreciate this fact and its limitations it is instructive to consider Eq. 8 in more detail. The equality in Eq. 8 says the vector (a, b, c) is perpendicular to the vector $(\dot{F}, \dot{D}, 1)$ which is tangent to the trajectory in F-D-T space, Fig. 8. The local surface in Fig. 3 is thus actually shaped rather more like a *fan* than a postage stamp. Linearity in $\dot{F}$ and $\dot{D}$ makes the fan a *plane* fan. The fan exhibits all the possible directions of subsequent straining at a point.

Consider a point (F, D, T) in the reachable region of F-D-T space. Pass axes through (F, D, T) parallel to the F, D, T axes, call du a short excursion parallel to the D-T plane starting from any point on the F

axis, Fig. 9. Let θ be the angle made in the D-T plane by the projection of du into this plane and the T axis. Then $dT = du \cos\theta$, $dD = du \sin\theta$. The assumption of linearity in M can be stated in physical terms: If at any point on a line through (F, D) parallel to the T axis an incremental change in F, ΔF, consists of a unique component proportional to ΔD and a unique component proportional to ΔT, then M is linear in $\dot{F}$ and $\dot{D}$. Accordingly for the linear case take

$$dF = (P \sin\theta + Q \cos\theta)\, du.$$

This is a generalization of Hookean behavior: If Q is identically zero and P a constant then $dF/dD = P$, which is Young's modulus. For the linear case we take P and Q both functions of F and D.

Definitions. The spring line is a unique line in the F-D plane which is the locus of (F, D) pairs for which $\dot{F} = 0$ and $\dot{D} = 0$. The spring surface is a unique cylinder in F-D-T space, perpendicular to the F-D plane, whose trace on the F-D plane is the spring line.

Let $Q(F, D)$ be representative of the distance from the point (F, D, T) to the spring surface. Then $Q(F, D) = 0$ is the equation for the spring surface. For points (F, D, T) on the $+F$ side of $Q = 0$, $Q(F, D)$ is negative for physical reasons, namely, the stress decays in time if $\dot{D} = 0$. For points on the opposite side of $Q = 0$ from $+F$, $Q(F, D)$ is positive since the stress increases with time if $\dot{D} = 0$. The sketch in Fig. 10 is for a point below the spring surface since Q is plotted as positive. It is clear from the sketch that

$$dF = (P \sin\theta + Q \cos\theta)\, du,$$

$$\frac{dF}{dt} = P \frac{dD}{dt} + Q,$$

$$\dot{F} = P\dot{D} + Q \text{ which is of the form}$$

$$M(F, D, \dot{F}, \dot{D}) = a\dot{F} + b\dot{D} + c = 0, \quad \text{if } P = -b/a,\ Q = -c/a.$$

P is the tangent of the dihedral angle formed by the D-T plane and a plane, p, perpendicular to the F-D plane and passing through the T axis. Q is the tangent of the trace on the F-T plane of the dihedral angle between the plane p and the trajectory fan. As shown in the sketch, Fig. 10, the vertex of this dihedral angle lies in the F-D plane, and this is a property of the linearity of M.

It is clear from Fig. 9 that $\tan\theta = dD/dT$, so that θ is a measure of the rate of strain of the fiber. Reference to Fig. 10 shows that Q is the rate sensitive or dissipative component in dF for if $Q = 0$ only elastic behavior is possible—the trajectory fan then being perpendicular to the F-D plane. P is the elastic component in dF since it measures the amount of upward tilt of the trajectory fan in the $+D$ direction irrespective of the amount of tilt in the $+T$ direction. The elastic component is frequently called the instantaneous component in the literature on the

subject, even though the dissipative component occurs simultaneously with it.

If either P or Q or both are functions of θ also then different types of non-linearity are introduced into M. One type, preserving the separation of dF into elastic and dissipative components has $P = P(F, D)$, but $Q = Q(F, D, \dot{D})$. This keeps the plane p in Fig. 10 but puts wrinkles into the trajectory fan, Fig. 11. Thus the dissipative component is different for different $\dot{D}$'s instead of being independent of $\dot{D}$ as in the linear case.

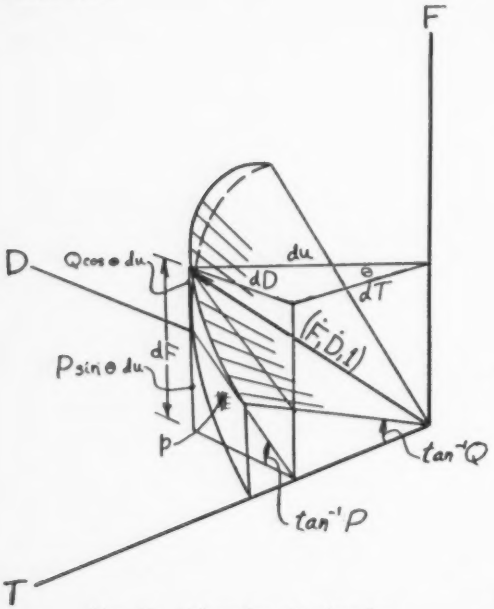

FIG. 10. Orientation of a plane fan.

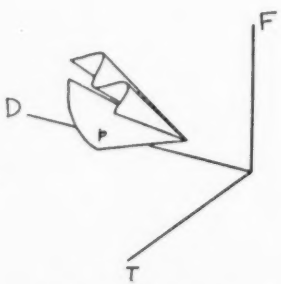

FIG. 11. Additive elastic and dissipative forces, but not linearly.

If the wrinkles in the trajectory fan are of small amplitude, or if the spread of the fan is not great, the trajectory fan can be approximated by its tangent plane fan which, if it intersects plane p in a line approximately parallel to the F-D plane, allows the non-linear M to be approximated by a linear M. The spread of the fan is determined from the useful technological range of strain rates: If the fiber is to be subjected to a wide range of strain rates a wide spreading fan is needed in the description, and conversely for a narrow range of strain rates.

Other types of non-linearity do not preserve the natural separation into additive elastic and dissipative components. But as long as trajectories lie in surfaces locally, a system of fans will exist, odd though their shapes might be. A fan grows out of every point in the reachable volume of F-D-T space. All fans on lines parallel to the T axis are

exact duplicates, because T does not enter M explicitly. At a fixed point, (F, D), the expression $M(F, D, \dot{F}, \dot{D}) = 0$ reduces to a function of $\dot{F}$ and $\dot{D}$ only. A slight change in $\dot{D}$ is accompanied by a slight change in $\dot{F}$ to satisfy the equality $M = 0$. The local surface, cone-like in nature, is swept out by the trajectory tangent vector during these changes in its components $\dot{F}$ and $\dot{D}$. In the linear case the surface is a plane. In the non-linear case the surface acquires curvature and becomes wrinkled. That it remains a surface can be stated mathematically: $\dot{F}$ and $\dot{D}$ are functions of a single parameter at a given point (F, D). This parameter can be taken as $\dot{D}$ itself for fiber theory, and implies that the fans are single valued surfaces over the D-T plane in the F-D-T space.

If $\dot{F}$ and $\dot{D}$ are functions of two parameters, then a multiplicity of fans will grow out of each (F, D, T) point—one parameter identifies a

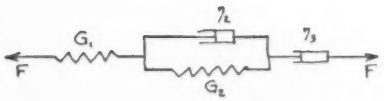

FIG. 12. Alfrey's 4 parameter model (1, p. 125).

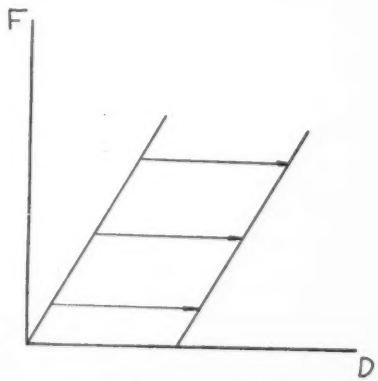

FIG. 13. Alfrey's 4 parameter model describes a continuously translating spring line.

fan, the other identifies an element of that fan. The trajectories are no longer constrained to lie in a surface locally. M must contain both of the identifying parameters, one of which can be either $\dot{D}$ or $\dot{F}$, the other one we call λ. The stress-strain relationship now becomes $M(F, D, \dot{F}, \dot{D}, \lambda) = 0$. Necessary physical or mathematical conditions for λ to satisfy are almost entirely unknown. But the existence of another parameter in M now makes possible a connection between this approach to visco-elasticity (via differential equations) and the approach via integral equations. For example, λ could be an integrated weighing of the completed trajectory to a given point which would then determine which fan leading out of the point the trajectory would take, while $\dot{D}$ would determine which element of the fan the trajectory would take.

Alfrey's 4 parameter model, Fig. 12, is an elementary example of $M(F, D, \dot{F}, \dot{D}, \lambda) = 0$. In terms of the parameters of Fig. 12, M

becomes

$$\eta_2\eta_3\dot{F} - G_1\eta_2\eta_3\dot{D} + [G_1(\eta_2 + \eta_3) + G_2\eta_3]F - G_1G_2\eta_3D + G_1G_2\int_0^t F(s)ds = 0. \quad (9)$$

Equation 9 describes a fiber whose spring line is continually shifting bodily to the right, Fig. 13, by an amount proportional to $\lambda = \int F$.

THEORY UNDERLYING EXPERIMENTS

The central purpose of experiments, in the context of the theory presented in this paper, is to determine if any equation of the form $M(F, D, \dot{F}, \dot{D}) = 0$ describes the mechanical behavior exhibited by a fiber. If the answer is yes the problem becomes that of finding the form of M. All that is expected of the equation is a description of the working of a fiber in the sense that $\sigma = E\epsilon$ is a mathematical description of the working of steel. A satisfactory theory is able to *complete the trajectory* once the arbitrary part is specified. If D, for example, is given as a function of T, the equation $M = 0$ should yield $F = F(T)$, or D if F is given. Within the assumptions of the theory, all the important mechanical behavior attributed to the visco-elastic substance should be available from the one equation, which could then validly be called the Stress-Strain relation.

An equation of the type $M(F, D, \dot{F}, \dot{D}) = 0$ represents a unique field of fans (or cones as they are called in the literature on the subject). Departures from uniqueness then provide the key for deciding if any M exists for the fiber. If, experimentally, the fans can be shown to be not unique we conclude that no differential equation provides the desired description. On the other hand if the fans are *unique enough* for technological application (that is, accurate to within 5 or 10 per cent) then the way is clear for an experimental construction of M.

The commonest evidence for non-uniqueness is permanent set in the fiber after it has been worked. More precisely if different mechanical cycles produce different amounts of permanent set this provides clear evidence of non-uniqueness. A cut through the reachable volume of F-D-T space by a plane $F = 0$ exposes the orientation of the array of fans. They all point toward the spring surface, which intersects $F = 0$ at $D = 0$, Fig. 14.

A fiber exhibiting permanent set follows a trajectory on the $F = 0$ plane somewhat as shown by the heavy curved line of Fig. 14. Such a trajectory is clearly not tangent to the isoclines, and makes obvious the inadequacy of the field of fans shown in Fig. 14. Of course the isocline field is not generally known beforehand and the experimental problem is to determine uniqueness without any prior information about the orientation of the fans. If two experimental trajectories can be made to cross on the $F = 0$ plane then necessary evidence for non-uniqueness will

have been obtained. This is the case when different mechanical cycles produce different amounts of permanent set, Fig. 15.

Similar experiments on D = constant planes can also demonstrate non-uniqueness. This is accomplished in the laboratory by terminating two different mechanical cycles by the same constant jaw separation and observing if the asymptotic values of F are equal.

But permanent set type experiments are special cases of non-uniqueness—occurring on planes F or D = constant. Non-uniqueness can also occur within the reachable volume of F-D-T space as well as on its

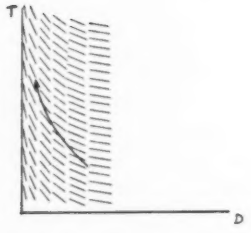

FIG. 14. Isoclines exposed by a cut $F = 0$.

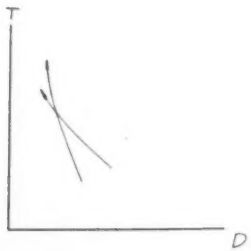

FIG. 15. Intersecting trajectories demonstrate non-uniqueness of the fan array.

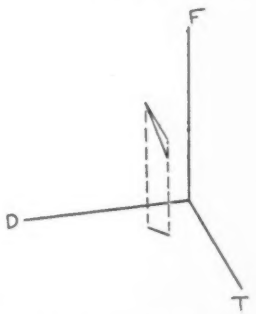

FIG. 16. Two trajectories with the same trace in the D-T plane.

bounding surfaces. Two trajectories lying directly over each other as in Fig. 16 give evidence of non-uniqueness. An experiment in which just this happens is described later in this paper.

CONSTRUCTION OF M IN THE LABORATORY

If a number of experiments show no serious non-uniqueness in the fan array, it becomes profitable to construct an M in the laboratory. It is necessary to measure the orientation of the fans all over the reachable area of F-D space. Since the orientation is continuously changing, one can only sample the orientation with a grid whose fineness will depend on the labor available for the project at hand. At a single point of the grid (and essentially the same procedure is followed at the other points) let us try for a plane fan. To measure the orientation of a plane at any point, (F, D), one need pass a minimum of three trajectories through the point at different rates. The volume of the parallelepiped spanned by the tangent vectors to the trajectories at (F, D) should be zero, that is, at the point (F, D) the determinant of the matrix

$$\begin{pmatrix} \dot{F}_1 & \dot{D}_1 & 1 \\ \dot{F}_2 & \dot{D}_2 & 1 \\ \dot{F}_3 & \dot{D}_3 & 1 \end{pmatrix}$$

should be zero. This experiment can be quite conclusive if suitable precautions are observed. Variability in the visco-elastic sample and impossibility of measuring F, D, $\dot{F}$, $\dot{D}$ exactly can all be overcome by duplicating the work several times independently, calculating the volume each time, and then inquiring if the mean of the volumes so calculated deviates from zero by an amount greater than one would expect from random fluctuations alone. If a non-planar fan is indicated, it can be approximated by a number of triangular shaped plane fans, Fig. 17.

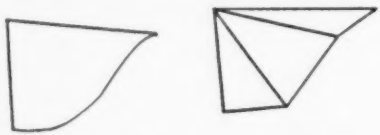

FIG. 17. Approximating a non-planar fan.

Alternatively one can consider the trace of the tangent vectors on the unit sphere centered on (F, D). For a plane fan the tangent vectors should pierce the sphere on a unique arc of a great circle. A least squares regression plane can be passed through the points and forced through the center of the sphere, and then well known statistical tests can be applied (provided enough trajectories are passed through the point), and a decision reached as to whether any of the trajectories deviates significantly from the plane.

AN EXPERIMENT

The purpose of the experiment described here is to demonstrate the operational feasability of the theory discussed so far by actually carrying out one of the test procedures described earlier. A sample of tire cord rayon, unworked and untreated in any way, was studied to determine if the field of trajectory fans is unique, uniqueness being a necessary condition for the valid description of the field by a relation of the type $M(F, D, \dot{F}, \dot{D}) = 0$. The procedure consists simply in experimentally fixing three of the arguments of M, say F, D, $\dot{F}$, and observing if the fourth one, $\dot{D}$, is likewise fixed. Practically, this is accomplished by considering one point in the F-D plane, say $F = F^*$, $D = D^*$ and passing two trajectories through it with the same $\dot{F}$'s, say $\dot{F} = \dot{F}^*$, but each trajectory having a *different prior history*. If the two trajectories pass through the point with different $\dot{D}$'s, we conclude that non-uniqueness has been demonstrated. It is not essential that F, D, and $\dot{F}$ be fixed; F, D, and $\dot{D}$ could be fixed, then differing $\dot{F}$'s would demonstrate non-uniqueness.

Accordingly, two trajectories, the f and the k, were sent through $D^* = 1.0\%$, $F^* = 0.23$ grams/grex, at the force rate $\dot{F}^* = -0.42$ gram/grex/sec. The two measured strain rates were $\dot{D}_f = -0.42\%$/sec, and

$\dot{D}_k = -0.52\%$/sec. As seen in the F-D plane, the slopes are $\dot{F}^*/\dot{D}_k = 0.814$ and $\dot{F}^*/\dot{D}_f = 1.00$. The experiment was repeated independently seven times, producing the data shown in Table I, from which the figures quoted above are taken.

TABLE I.

Run	D, %	F, g/gx	$-\dot{D}$, %/sec.	$-\dot{F}$, g/gx/sec.
1*k*	0.99	0.23	0.52	0.42
2*k*	1.00	0.23	0.55	0.42
3*k*	1.10	0.23	0.49	0.44
4*k*	1.02	0.23	0.52	0.42
5*k*	1.05	0.23	0.51	0.41
6*k*	0.94	0.23	0.50	0.43
7*k*	0.97	0.23	0.58	0.43
Average	1.01	0.23	0.52	0.42
1*f*	1.10	0.23	0.39	0.41
2*f*	1.07	0.23	0.44	0.41
3*f*	1.07	0.23	0.44	0.43
4*f*	0.96	0.23	0.44	0.44
5*f*	1.12	0.23	0.45	0.42
6*f*	1.10	0.23	0.38	0.43
7*f*	1.10	0.23	0.41	0.40
Average	1.07	0.23	0.42	0.42

The differences between the f and k averages for D, F, and $\dot{F}$ are not significant (0.95 confidence level), while the difference between the $\dot{D}_f$ average and the $\dot{D}_k$ average is highly significant statistically and rheologically. Both f and k trajectories started at (0, 0), their subsequent routes as seen on the D-t plane are shown in Figs. 18 and 19.

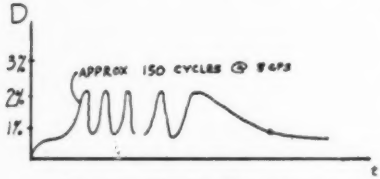

FIG. 18. The f loading pattern.

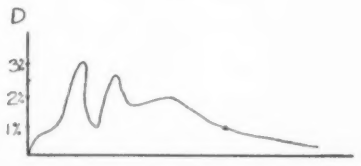

FIG. 19. The k loading pattern.

It is clear that f represents a work hardening pattern while k leaves the fiber soft. The steeper slope on the F-D plane for the f trajectory than the k trajectory is a quantitative measure of the hardening effect. We thus show that virgin rayon cannot be described by a smooth (C') equation like $M(F, D, \dot{F}, \dot{D}) = 0$. The non-uniqueness of the trajectory fan can be demonstrated in other parts of the reachable region of F-D-T space. For viscose rayon such non-uniqueness is the rule rather than the exception.

Acknowledgments

Thanks are due Drs. W. H. Hoppman II and Francis Clauser of the Johns Hopkins University for valuable comments and criticisms, and Dr. C. J. Geyer, Jr. of the American Viscose Corporation for making this paper possible.

APPENDIX

Notation

D as used in this paper is $(L\text{-}Lo)/Lo$ where $L = L(T)$ and $Lo = L(0)$. Then $\dot{D} = \dot{L}/Lo$. This is the simplest measure of strain and strain rate which can be used in the laboratory. It specifies in a unique way the amount of extension in a one dimensional specimen, similarly $\dot{D}$ tells the rate at which this extension is homogeneously inserted. These properties of D and $\dot{D}$ are not limited to small strains or low strain rates. The notation D is used because it is essentially *displacement* of one end of a filament with respect to the other end. The main objection to using D and $\dot{D}$ is that they cannot be generalized to three dimensions if they are not infinitesimal. Hence they are practically worthless in a quantitative theory of three dimensional viscoelasticity.

F is the force in the fiber per unit of linear density of the original unstressed fiber. The unit of linear density, the grex, is the weight (in grams) of a 10,000 meter length of the filament. Force as used here has, therefore, the dimension of length. This peculiar state of affairs only makes sense if one regards fibers as one dimensional bodies sot hat a unique mapping exists between weight (force) and length. The linear density is effectively a measure of the cross-sectional area of the fiber as long as one is talking about fibers made of the same material. This cross-sectional area contracts as tension increases in the fiber, the grex decreases, the grams/grex therefore increase even faster than the over-all tension increases. Many workers in the fiber field attempt to apply a correction and hence obtain an unbiased estimate of the true stress in the fiber. Such an adjustment is illogical given the assumption of one-dimensionality, nor does it improve one's understanding of the phenomena taking place. Fibers are made of long chain molecules, and as the fiber is loaded the same molecules bear the load and presumably pass through a given cross-section even as they did before the loading commenced. There is, therefore, also a practical, common sense reason for using *original* grex throughout an experiment rather than guessing current grex.

Physical Assumptions

Assumptions about the physical nature of the material being studied are as follows. The theory probably can be applied to a wider class of matter but this is what is specifically in mind in this paper. We call these the assumptions of Simple Fiber Theory, or the Simple Fiber Hypothesis.

f1. No spatial effects. There are no space gradients, all strains are homogeneous, all rates affect all portions of any experimental fiber equally and simultaneously, that is, all quantities are densities. The spatial extent of the fiber is assumed to occupy only one dimension, and to be homogeneous in that dimension, hence transverse variations in fiber properties are ignored though plainly visible in some photomicrographs of cross-sections.

f2. No inertial effects. The forces of elasticity in fibers are so much greater than the force response to inertia that it is a minor error indeed to neglect the latter.

f3. Temperature and humidity are regarded as perturbations on the basic mechanics—perturbations, however, whose effects are of the same order of magnitude as the basic mechanics. Constant Temperature and Humidity are implied in experiments unless otherwise stated. The aim is to describe mechanical behavior in mechanical terms only.

f4. No structural effects. Not included in this theory are the effects of intertwining fibers and thus putting curvature into them or otherwise rendering them non-homogeneous. Nor can surface finish on the fiber be considered.

f5. No molecular assumptions. This is a continuum theory in which molecular speculations are deliberately avoided and gross phenomena are described by gross variables and gross hypotheses alone.

Mathematical Assumptions

In *F-D-T* space (Cartesian coordinates, $F \geq 0$, $D \geq 0$, $T \geq 0$):

m1. A set of points can be reached via trajectories starting at (0,0,0).

m2. The trajectories form surfaces locally, that is, different trajectories through the same point (F,D,T) at different rates form a surface in the neighborhood of (F,D,T).

Discussion of Assumptions

Assumption m2 says that in the reachable region of *F-D-T* space there is attached to each point a *fan* or Monge *cone* which exhausts all possible directions for subsequent straining. Essentially m2 states that some functional relationship $M[F(T), D(T), \dot{F}(T), \dot{D}(T)] = 0$ exists and is a smooth enough function of all its arguments for the mathematical operations to which it is to be subjected.

Assumptions f1 and f2 place *acoustic limits* on the spread of the fans. Accordingly, the velocities of propagation of burgeoning stress and relaxing stress respectively determine the range of strain rates which are considered.

Transformations of M

There is a transformation (4) which changes the underdetermined equation M containing F and D as independent functions of T, into a partial differential equation, $\mathfrak{F}$, containing F as a function of D and T. The transformation consists in eliminating $\dot{F}$ and $\dot{D}$ from the set of equations:

$$M(F,D,\dot{F},\dot{D}) = 0$$
$$F_D = -\, M_{\dot{D}}/M_{\dot{F}}$$
$$F_T = \dot{F} - F_D\dot{D}$$

in which

$$F_D = \partial F/\partial D$$
$$M_{\dot{D}} = \partial M/\partial \dot{D}$$
$$M_{\dot{F}} = \partial M/\partial \dot{F}$$
$$F_T = \partial F/\partial T.$$

This produces the partial differential equation $\mathfrak{F}(F,D,F_T,F_D) = 0$. The characteristics of this partial differential equation are the surfaces mentioned in assumption m2.

M can be obtained from $\mathfrak{F}$ using the equations for the characteristics, that is, by eliminating F_D, F_T from

$$\mathfrak{F} = 0$$

$$\frac{dT}{\mathfrak{F}_{F_T}} = \frac{dD}{\mathfrak{F}_{F_D}} = \frac{dF}{F_T\mathfrak{F}_{F_T} + F_D\mathfrak{F}_{F_D}}$$

in favor of dD/dT and dF/dT.

By making assumption m2, the theory of visco-elasticity in simple fibers is reduced to the theory of 1st order partial differential equations. The theory of such equations has been studied quite extensively in an effort to find solutions to given equations and boundary conditions. But the rheological application of the theory brings a seldom studied inverse problem: Given an array of solutions to an unknown differential equation what can one conclude about the form of the equation?

Experimental Apparatus

The requirements of the apparatus are that it produce usably accurate traces of $F(t)$ and $D(t)$. $\dot{F}$ and $\dot{D}$ are then obtained by graphical differentiation of the F and D traces.

The $D(t)$ trace is produced as shown schematically in Fig. 20. The fiber sample, 800 millimeters in length, is held between two clamps. To one of the clamps is bolted a paper

transporting device which moves a strip of graph paper at constant speed transverse to the fiber axis. To the other clamp, by means of a fitting, a ¼-in. aluminum tube is rigidly attached. This tube parallels the fiber, passes through guides on the paper transport device and terminates there after providing a means of supporting a recording stylus which bears lightly against the paper. The paper is black with a white coating and was obtained from the Sanborn Company, Cambridge, Massachusetts. In use, the coating is scratched off by the stylus leaving a black line about .003" wide on a white background. This apparatus can record detailed motion up to about 20 cps. at about 15-mm. amplitude. Eight mm. corresponds to $D = 1\%$.

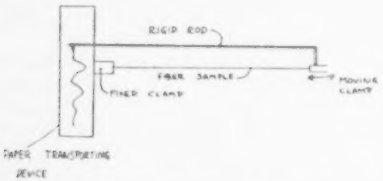

FIG. 20. Line diagram of D recorder.

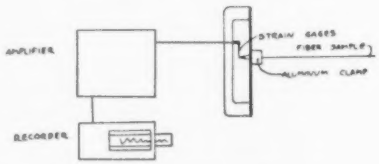

FIG. 21. Line diagram of F recorder.

The $F(t)$ trace is produced as shown schematically in Fig. 21. The fibers were studied 900 at a time, having a total grex of 1830. The specimen was a flat ribbon of filaments with no twist. The specimen was held in a snubbing type clamp made of aluminum which was bolted to the center of a fixed-fixed beam. The elastic deflections of the center of the fixed-fixed beam were proportional to F, the force in the fibers. These deflections were directly transmitted by a rigid pin pressing against a cantilever beam made of stainless steel ribbon in such a way that the cantilever was unloaded as F increased. SR-4 resistance strain gages were cemented to the cantilever. Signals from the gages were amplified by a Brush BL-320 amplifier and printed by a direct inking Brush recorder. Timing markers driven by a common breaker provided simultaneous marks on both $D(t)$ and $F(t)$ records.

The load was applied by means of a pneumatic jack-hammer arrangement at the movable clamp. Adjusting the spring constants, the masses, and the air pressure can produce a variety of loading patterns.

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THE CHEMICAL SOCIETY OF PHILADELPHIA AND CERTAIN LOCAL INSTITUTIONS *

BY

JOSEPH SAMUEL HEPBURN [1]

Both The Franklin Institute and the University of Pennsylvania, founded almost a century apart, have a close connection with another Philadelphia institution—the Chemical Society of Philadelphia. That Society drew its membership almost entirely from the student body and the faculty of the University, and at least four of its members became original or early members of The Franklin Institute. In order to make the story complete, the evolution of the University from the Charity School of 1740, and the early history of The Franklin Institute must be reviewed.

The Chemical Society of Philadelphia, "instituted 1792," is usually considered to have been the first or oldest chemical society in the world. It was so designated by Bolton (1)[2] and by Smith (2, 3, 4, 5). Miles (6) has reported the existence of an earlier, unnamed chemical society in Philadelphia in 1789;[3] and Kendall (7) has noted the existence of chemical societies at two Scotch universities, at Edinburgh in 1785 and at Glasgow in 1788–1789.[4]

However, the Chemical Society of Philadelphia was the first in the world to issue publications, at least three of which are known:

1. "A Sketch of the Revolutions in Chemistry" (13), by Thomas P. Smith. This was the annual oration delivered before the Society in 1798, and published by it in that year.

* Presented before the City History Society of Philadelphia, February 15, 1955.

[1] Archives Researcher, The Franklin Institute; Professor of Chemistry and Research Associate in Gastroenterology, Emeritus, The Hahnemann Medical College and Hospital of Philadelphia; President, City History Society of Philadelphia.

[2] The boldface numbers in parentheses refer to the references appended to this paper.

[3] This society was described briefly by James Cutbush (8) who states that it was organized in 1789, and had as its president "the late Dr. J. Pennington." Penington (his family name is so printed on his dissertation for the doctorate in medicine (9) in 1790 at the College of Philadelphia, now the University of Pennsylvania), was a victim of the yellow fever epidemic of 1793 in Philadelphia (10). His researches on the occurrences of sugar in the blood and on alcoholic fermentation are described in the third paper of this series, "Pioneer Biochemical Researches at the University of Pennsylvania."

[4] Kendall (11) states that the "List of the Members of the Chemical Society" at Edinburgh was preserved in the correspondence of Joseph Black, dated in his handwriting 1785, and contains 59 names of persons of whom 58 were students in Black's classes in chemistry in Edinburgh 1780–1788, and 19 were graduated by that university in medicine 1784–1790. Butler (12), from statements in the biographies of certain of its members, gives the date of the Glasgow society as 1786. Kendall (11) also cites a published journal (diary) and a published letter to show the existence of a chemical society at London in 1782, and at Manchester prior to 1787.

2. "Annual Oration Delivered before the Chemical Society of Philadelphia" (14), by Felix Pascalis. This oration, delivered in 1801, was published by order of the Society in 1802.
3. "Memoir of the Supply and Application of the Blow-Pipe" (15), by Robert Hare. This paper, presented before the Society, was published by its order in 1802.

The activities of the Chemical Society of Philadelphia are recorded in the contemporary professional press, newspapers and other publications. Miles (16) has collected these references to the Society and its activities, and has also compiled, with his authority in each case, a list of 70 members of the Society.

Up to 1806, at the University of Pennsylvania dissertations for the degree of doctor of medicine were printed (17) as those for the doctorate in philosophy are now printed. Miles (16) found membership of the author in the Chemical Society of Philadelphia stated on the title pages of their respective dissertations by at least 54 of these graduates in medicine of the University.

The Chemical Society of Philadelphia was "instituted 1792" and held "stated meetings once a week" (18). Its meeting place (19) was Anatomical Hall, also called Surgeons Hall, or the Philadelphia Laboratory, which was the home of the department or school of medicine of the University of Pennsylvania prior to 1806, containing its laboratories of anatomy and chemistry. It was replaced in 1840 by a house designated No. 131 South Fifth Street.[5]

This society flourished for over a decade under the guidance of Woodhouse. According to John Redman Coxe, it "was broken up" during the life time and professorship of Woodhouse.[6]

UNIVERSITY OF PENNSYLVANIA

In view of the close affiliation of the members of the Chemical Society of Philadelphia with the present University of Pennsylvania, it is desirable to give an outline of the history of that institution which traces its origin to the year 1740. At that time the religious revival known as the Great Awakening was in progress. George Whitfield (also written Whitefield) the evangelist, required a suitable place of worship, since many of the local clergy were antagonistic, the local churches were inadequate for his congregation, and the weather at

[5] This site is now included in the Independence National Historical Park. The last occupant of the site was a newspaper, known as the *Jewish Daily Forward*. Birch (20) depicted Surgeons Hall in the views of Philadelphia.

[6] James Woodhouse, founder and president of the Chemical Society of Philadelphia was the custodian of the electrical machine and John Redman Coxe was the author of the letter of presentation discussed in the first paper of this series, "How Franklin's Electrical Machine Came to The Franklin Institute."

The dissertation of Woodhouse, a biochemical study of the persimmon, is summarized in the third paper, "Pioneer Biochemical Researches at The University of Pennsylvania."

times interfered with services in the open air. Accordingly, a fund was raised, and a non-sectarian body of unincorporated trustees took title to a plot of ground and erected thereon a building, known as the New Building, for a charity school and a place of public worship wherein Whitfield and such Protestant ministers should preach as were "sound in principle, zealous, and faithful in the discharge of their duty, and acquainted with the religion of the heart, and experimental piety," without regard to distinctions in lesser matters. The deed to the land is dated September 15, 1740 (21). The approximate site of the New Building is marked by a tablet on the south wall of 62 North Fourth Street, in the driveway immediately south of that building.

Death created a vacancy in the Board of Trustees; and Benjamin Franklin, as he relates in his "Autobiography" (22), was nominated as "merely an honest man, and of no sect at all," and was elected to fill the vacancy.

In 1749, Franklin published his "Proposals Relating to the Education of Youth in Pensilvania" (23). He records in his "Autobiography" (22) how funds for an academy were raised by subscription, and the subscribers chose out of their number twenty-four trustees. The "Constitutions of the Publick Academy In the City of Philadelphia," named as Trustees twenty-four persons, one of whom was Benjamin Franklin (24). On November 13, 1749, the Trustees met, read, approved, and signed the Constitutions, and organized. Franklin was elected president for the ensuing year, and a committee was appointed "to treat with the Trustees of the New Building, about taking a part of it for an Academy." On December 26, 1749, agreement for transfer of the New Building was reached by the two boards of trustees. On February 1, 1750, at a joint meeting of the two boards, those of the New Building "accordingly did convey the said Building Lott of Ground and Appurtenances, to the Trustees of the Academy" who paid 775 pounds, 18 shillings 11 pence and 3 farthings to discharge the debts and incumbrances of said building &c. Franklin states (22) that as a "member of both setts of trustees" he brought them finally to an agreement; and the title to the property was transferred, subject to the trusts for a charitable school and for religious services.

On July 13, 1753, "Thomas Penn and Richard Penn, Esquires, true and absolute Proprietaries and Governors in Chief of the Province of Pennsylvania and Counties of Newcastle, Kent & Sussex on Delaware" granted a charter of incorporation to "The Trustees of the Academy and Charitable School in the Province of Pennsylvania." The charter was recorded July 16, 1753 (25).

On May 17, 1755, Thomas Penn and Richard Penn, as Proprietaries, granted an "additional charter." The corporation became the "Trustees of the College, Academy and Charitable School of Philadel-

phia in the Province of Pennsylvania," and was empowered to confer university degrees. This charter was recorded June 16, 1755 (26).

In both charters (1753 and 1755), Benjamin Franklin is mentioned as one of the trustees.

During the Revolutionary War, in 1779, by legislative enactment, the board of trustees and the faculty under these proprietary charters were "dissolved and vacated." "The Trustees of the University of the State of Pennsylvania" were created, and vested with the powers and property of the College, Academy and Charitable School (27). This act named certain trustees *ex-officiis*, and certain persons by name as trustees; among the latter was "the honorable Benjamin Franklin, doctor of laws, minister plenipotentiary from the United States of America to his most Christian Majesty." This was the first American institution of higher education to possess the corporate title of university, and was the first state university.

Another law, passed in 1789 (28), reinstated and restored to the Trustees under the proprietary charters the franchises, trusts, and estates which they had possessed and designated them "The Trustees of the College, Academy and Charitable School of Philadelphia in the Commonwealth of Pennsylvania." On March 9, 1789, "the first Meeting of the Trustees was held at the House of Dr. Franklin, upon due Notice given by Dr. Smith the former Secretary, by order of Dr. Franklin the Senior Member to all the Surviving Trustees, being fourteen in Number, viz: Benjamin Franklin LL.D—One of the Founders in 1749..." At this meeting, "The Body being now duly organized & assembled, proceeded in the first place to the Election of a President, and the venerable Dr. Franklin the Father and one of the first Founders of the Institution was unanimously elected." Those present included Franklin, ten other trustees, and "the Rev'd William Smith D.D. Provost of the College, and Secretary of the Board of Trustees" (29).

The Board also held its meeting at Franklin's house on March 11 and July 27, 1789, thereafter at the College "on Account of his present low State of Health." "The Presidt." (Franklin) attended a meeting of the Board on October 21, 1789 (29).

The College and the University of the State each conducted a collegiate department and a medical school; the College also gave instruction in law. The two institutions reached an agreement on terms of union, and were united by an Act of Assembly in 1791 under the present corporate title the "Trustees of the University of Pennsylvania" (30).

THE CHEMICAL SOCIETY OF PHILADELPHIA AND THE UNIVERSITY OF PENNSYLVANIA

James Woodhouse, professor of chemistry in the University of Pennsylvania from 1795 until his death in 1809, was the first and only president of the Chemical Society of Philadelphia.[7] It became inactive

[7] See footnote 6.

before his decease. The era in which it existed probably was a factor in its termination.

Upon comparison of Miles' list of members of the Society (16) with the list of graduates of the medical department of the University of Pennsylvania (31), it is found that, of those graduating in medicine between the years 1792 and 1811, both inclusive, 59 were members of the Society. They came from the following geographical divisions: Georgia 2, Louisiana 1, Maryland 5, New Jersey 2, North Carolina 2, Pennsylvania 21, South Carolina 11, Virginia 10, Brabant 1, Ireland 1, St. Croix 1, Tortola 1, West Indies 1. None of the members graduated from the University in medicine prior to 1792 or after 1811.

Eight additional members of the Society were connected with the University. Redman was a trustee, and Priestley and Patterson were members of the faculty, while five members, not included in the medical graduates, had attended the University, as related below.

John Redman was a trustee of the College, Academy and Charitable School of Philadelphia from 1762 to 1791 (34), graduated in medicine at Leyden in 1748, was a founder and the first president (1786–1805) of the College of Physicians of Philadelphia (35), and is mentioned as an incorporator and president of that College in its legislative charter in 1789 (36). He served (1791–1796) as president of the Presbyterian Ministers' Fund, the oldest chartered life insurance company in the world (37).

Joseph Priestley (32, 33) was elected to the professorship of chemistry in the University in 1794, but declined the chair in 1795.

Robert Patterson and his activities as scientist and educator are described below.

During the present research, new evidence has been found in the archives and alumni records of the University demonstrating that Brown, Lee, Bryant, Smith, and Hare had been students in the University.

The records in the Alumni Records Office of the University of Pennsylvania reveal that Thomas Brown attended its medical school during the session of 1801–1802, and that George Lee graduated from the University as a Bachelor of Arts in 1795 and attended its medical school during the session of 1800–1801.

John Y. Bryant received the degree of Master of Pharmacy from the University of Pennsylvania in 1821. The letter in which he applied for that degree has been preserved in the Archives of the University, and reveals that he attended the lectures of Woodhouse and of Barton, and had been an active member of the Chemical Society of Philadelphia. He wrote:

> Professor Coxe
> Dean of the Faculty
> University of Pennsa.
>
> Sir,
>
> Highly approving of the resolutions of the University of Pennsa. instituting the Degree of Master of Pharmacy—I wish you to consider this, as my application for said Degree.

My claims to this distinction are, That I was under the instruction of Mr. George Hunter Chymist & Druggist, formerly of this City, about Seven Years; for several Years of this time, the operations in his Laboratory were chiefly under my care and direction; attended the Lectures of the late Professors Woodhouse and Barton; for some years an active member of the Chemical Society of Philada. and have been established in the Drug and Apothecary business about twenty three years.

With great consideration
and Respect
I am Yr Obdt
John Y. Bryant.

Phila. Mch. 14, 1821.

On the back is a notation: "agreed to by the Medical Faculty."

Thomas P. Smith[8] attended the University of Pennsylvania. The Roll Book of the Academy of the University of Pennsylvania for the period 1792–1802, now in the Archives of the University, records the attendance of Thomas P. Smith from early July to late December, 1792, in the Mathematical Schools. He then was approximately fifteen years of age. Smith dedicated his oration before the Chemical Society of Philadelphia in 1798 (**13**) to Robert Patterson, "the instructor of my early youth." Patterson (**38**) had been appointed, by the Trustees of the University of the State of Pennsylvania, a teacher of writing, arithmetic and mathematics in the Academy in 1779, and, in 1782, to the professorship of "Mathematicks" and as "master of a School for teaching Practical Mathematicks, Arithmetick and Book Keeping" (apparently the remote precursor of the present Wharton School). Patterson was elected professor of mathematics in the University of Pennsylvania in 1792 (**39**). Apparently Patterson taught Smith in the Academy. Smith was also a pupil of Benjamin Smith Barton, Professor of Materia Medica, Natural History and Botany in the University of Pennsylvania, who speaks of "My friend and pupil, the late Mr. Thomas P. Smith . . ." (**42**).[9]

Robert Hare attended both the Academy and the College departments of the College of Philadelphia. The Archives of the University of Pennsylvania contain a book "College and Academy of Philada. Account of Tuition Fees 1767–1791," being a written record of payments made for scholars by their parents or guardians. Robert Hare is listed as a scholar in the English School on July 1, 1789, and in the Latin School on January 1, 1791, with the notation "from E. Schl." His name appears several times in 1789 and 1790, but the records are headed "Latin & English Schools," and students in each school are not speci-

[8] His full name was Thomas Peters Smith. It is so stated in the record of his election in 1799 to the American Philosophical Society (**40**) of which he was an active member. Edgar F. Smith (**41**) gives the period of Thomas P. Smith's life as 1777–1802.

[9] In a recent paper, Duveen and Klickstein (**44**) have cited Thomas P. Smith's oration (**13**) as evidence of the acceptance by 1798 of the new chemical nomenclature of Lavoisier in America.

fically identified.[10] These entries in the account book reveal that Hare was a scholar in the English School of the Academy in 1789 and 1790, and then entered the Latin School of the College in 1791.

Carson (**43**) states concerning Hare: "At the age of twenty he entered the Chemical School of the University of Pennsylvania, where in association with Dr. Benjamin Silliman, he pursued his studies under the direction of Woodhouse."

Evidence exists that certain members of the Chemical Society of Philadelphia were students in the Chemical School of the University of Pennsylvania.

Cheyney (**47**) relates that, in the medical school of the University of Pennsylvania, the "ticket" for each course was sold in early times by the professor of the subject himself, later by the janitor, and that tuition fees were not paid to the corporation prior to 1877. Bryant had attended the lectures of Woodhouse as had Robert Hare. In their life of Benjamin Silliman, Fulton and Thomson (**48**) relate how Silliman attended the lectures of James Woodhouse in the Medical School of Philadelphia, that is, the University of Pennsylvania, They quote a letter written in 1802 to Benjamin Rush, then professor of the institutes of medicine and clinical medicine in that University, by Silliman, in which he finds it impossible to do justice to four courses of lectures and also make Chemistry a principal subject, decides to relinquish two courses and confine himself to Anatomy, chemistry, and midwifery, returns his ticket for Rush's course, and requests that his name be erased from Rush's list. Therefore, Silliman had purchased "tickets."

Since Thomas P. Smith had been a student in the Academy, was so closely associated with Woodhouse in the Chemical Society of Philadelphia, and with Robert Patterson and Benjamin S. Barton, it is reasonable to assume that Smith also received his chemical education under Woodhouse in the Chemical School of the University.

The students in the Chemical School apparently were those who did not pursue the entire medical curriculum, but purchased "tickets" for the course given by Woodhouse, and possibly for the courses of other professors, and, doubtless, like Silliman, spent more time on chemistry than did the regular medical students. Possibly, for this reason, Bryant, Hare, Silliman, and Thomas P. Smith do not appear among the former students of the University of Pennsylvania whose records are preserved in its Alumni Records Office; however, Bryant, Hare, and Smith, as mentioned above, appear elsewhere in the Archives of the University.

[10] The plan of education of the first Provost, William Smith, was first published in the *Pennsylvania Gazette* on August 12, 1756, and, up to 1900, had appeared in print at least six additional times (**45**), and has again appeared in 1951 (**46**). This plan provided that the Academy should include the English School and the School for practical branches of Mathematics; and that the College should include Three Philosophy Schools and the Latin and Greek Schools.

Only three of the 70 known members of the Chemical Society of Philadelphia were not connected with the University of Pennsylvania: Brison, Mrs. Fulhame, and Felix Pascalis. Only the family name of Brison[11] is known (16). Mrs. Fulhame, an English author, was a corresponding member. Felix Pascalis is listed in the Philadelphia directories (49, 50) as Pascalis, Felix, M.D. on Cedar or South Street. He was known also as Felix A. Pascalis-Ouviere. A native of Provence, and a graduate of Montpellier, he practiced medicine in St. Domingo until driven out by the slave insurrection of 1793, when he came to the United States. He practiced medicine in Philadelphia 1793–1810, then removed to New York where he died in 1833 (51, 52, 53). In his oration before the Chemical Society of Philadelphia in 1801, Pascalis mentions Priestley as a member of the Society.

The Society was not a mere organization of medical students. Its membership included more mature men: Priestley, Pascalis, Redman, Woodhouse, and Patterson. Its activities and publications, and the researches of its members were of professional status. Six of its members were or became fellows of the College of Physicians of Philadelphia; and sixteen of its members were or became members of the American Philosophical Society.

The termination of the existence of the Society doubtless was due to several factors. Of the members who graduated in medicine from the University of Pennsylvania, the greater portion returned to their homes to practice their profession. Travel was difficult and slow; and therefore return to Philadelphia to attend meetings of the Society was an impossibility, even for some residents of Pennsylvania.[12] Professional duties called some members far from Philadelphia.[13]

[11] This name does not appear in the Philadelphia directories for 1801, 1802 and 1803 (49, 50), the period in which Brison was a curator of the Society; also this name does not appear in the General Alumni Catalogue of the University of Pennsylvania issued in 1922.

[12] Thus, in 1794 five days were required to travel by cart, wagon, and canoe the distance of approximately 150 miles from Philadelphia to Priestley's home at Northumberland (54). In 1819 the journey from Philadelphia to Lexington, Kentucky, the site of Transylvania University, "rarely occupied less, and sometimes more than three weeks" (55).

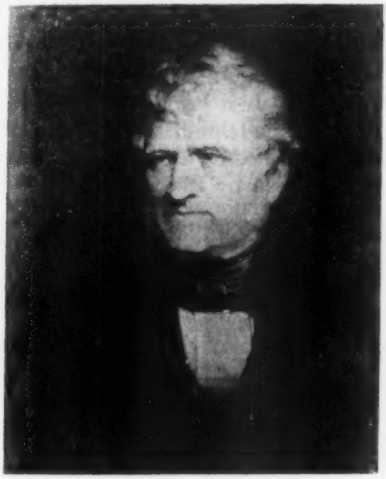
[13] Edward Cutbush (56) served as a surgeon in the United States Navy from June 24, 1799 until his resignation on June 10, 1829. Thomas Horsfield (57) entered the service of the East India Company, was a naturalist, author, and physician, conducted researches in botany, entomology, and zoology in Java, and became the first librarian of the East India House in London. Charles Caldwell was appointed professor of natural history in the University of Pennsylvania (58) in 1816 and resigned in 1820, then became professor of the institutes of medicine and clinical practice in Transylvania University 1819–1837, and was dean of its medical faculty (55, 59). Then he founded the Louisville Medical Institute (since 1846 the medical school of the University of Louisville) and served as its professor of the institutes of medicine, medical jurisprudence, and clinical medicine, 1837–1849 (55). The institutes of medicine were the fundamental principles of medical science; they have developed into physiology, pathology, and related subjects in the medical curriculum. Robert Hare was professor of natural philosophy in the College of William and Mary 1818–1819; and Patrick Kerr Rogers was professor of natural philosophy and chemistry in the same institution 1819–1828 (60). As related above, Felix Pascalis removed to New York (51, 52). William Bache in 1802 was a resident of Franklin, near Charlottesville, Virginia as mentioned in the first paper of this series.

THE CHEMICAL SOCIETY OF PHILADELPHIA AND THE EARLY FRANKLIN INSTITUTE

At its first meeting, on February 5, 1824, The Franklin Institute adopted this resolution:

> Resolved. That this Society shall consist of such persons as shall inscribe their names, on or before Monday the 16th instant; and of such persons as shall afterwards be elected in conformity to the Constitution. (61)

The original, as distinguished from elected, members of The Franklin Institute included three members of the Chemical Society of Philadelphia: John Redman Coxe,[14] Robert Hare, and Robert Patterson. Another member of the Chemical Society, Nathaniel Chapman, was elected a member of the Institute in 1831.



ROBERT HARE

Portrait, commenced by John Neagle in 1858 and completed by J. L. Williams in 1877, in the School of Medicine, University of Pennsylvania

ROBERT HARE

Mention has been made above of the education of Robert Hare in the University of Pennsylvania, his membership in the faculty of the College of William and Mary (60) and his oration on the oxyhydrogen blowpipe (15). He was elected professor of chemistry in the University of Pennsylvania on September 18, 1818 and served until his resignation which was tendered May 10, 1847 and accepted May 15, 1847 when he was appointed emeritus professor of chemistry by the Trustees (43).

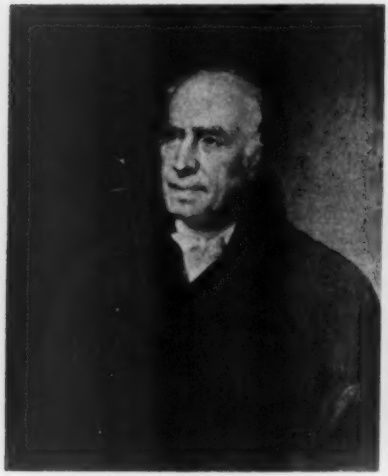
[14] The activities of Coxe have been described in the first article of this series, "How Franklin's Electrical Machine Came to The Franklin Institute"; his doctoral dissertation will be considered in the third article "Pioneer Biochemical Researches at the University of Pennsylvania."

An elaborate biography of Hare was written by Edgar F. Smith (3). From Hare's first invention, the oxyhydrogen blowpipe (15), evolved the oxyacetylene torch and the lime light; it made possible the fusion of platinum, and thereby simplified the metallurgy and working of that metal. Smith has stressed the researches of Hare as early worker in the field of electrochemistry. Hare used the mercury cathode, devised an electric furnace, and prepared calcium, strontium, barium, phosphorus, calcium carbide, and artificial graphite in the electric way. He also made contributions to gas analysis.

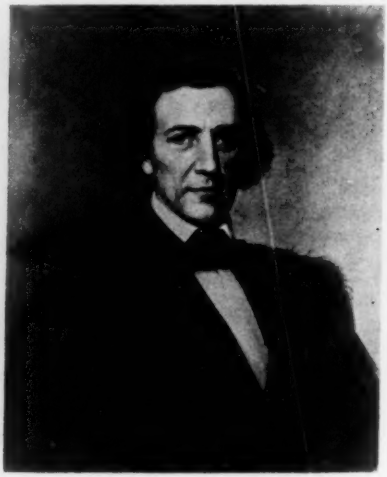
Hare was an original member of The Franklin Institute, and became a life member in 1828. In the cumulative index, covering the first sixty years of the JOURNAL OF THE FRANKLIN INSTITUTE, the name of Robert Hare is followed by 48 items (62). Hare was a native of Philadelphia, born January 17, 1781, and died May 15, 1858.

THE PATTERSONS

In the list of Miles (16) Robert Patterson is given as vice-president of the Chemical Society of Philadelphia. He was an original member of The Franklin Institute, was elected a member of its first Board of Managers in 1824, and was chosen by the Board as its first chairman (63).



ROBERT PATTERSON
Portrait by James R. Lambdin after Rembrandt Peale in College Hall, University of Pennsylvania



ROBERT MASKELL PATTERSON
Portrait by James R. Lambdin in College Hall, University of Pennsylvania

Robert Patterson was the son of Robert Patterson, the elder, was born near Hillsborough, Ulster, Ireland, May 30, 1743, arrived in Philadelphia in 1768, and died there July 22, 1824. He taught school

in Bucks County, Pa., Philadelphia, and Wilmington, Delaware, and conducted a country store in Bridgeton, New Jersey. In 1775–1776 he was adjutant in a Delaware regiment. During the Revolutionary War, he served with New Jersey troops (**64**). The Convention of New Jersey, on July 8, 1776, "Ordered, that Robert Paterson, Esq. be Surgeon's Mate to the battalion directed to be raised in the Counties of Burlington, Gloucester, Salem, and Cumberland, under the command of Colonel Silas Newcomb" (**65**). The family name should be Patterson. The official roster of New Jersey troops and militia (**66**) shows that Robert Patterson served as "Serjeant, Captain Newkirk's company, Second Battalion, Salem," "Surgeon's Mate, Colonel Newcomb's battalion, 'Heard's Brigade,'" and "Brigade Major, staff Brigadier General Newcomb." Du Bois (**64**) states of Patterson: "generally, from 1776 until the evacuation by the enemy, of Philadelphia and New Jersey, in 1778, he was on military duty; . . . A journal which he kept while in the army is unfortunately missing, and we are left without particulars of his tour of duty." He engaged in farming in Cumberland County, New Jersey until the end of 1779.

Mention has been made of the election of Robert Patterson to the faculty of the University of the State of Pennsylvania (**38**) on December 21, 1779, and of the University of Pennsylvania (**39**) on April 3, 1792 with assignment to the professorship of mathematics on April 9, 1792. The University of the State of Pennsylvania conferred on him the degree of Master of Arts in 1788 (**38**).

On November 6, 1810, his academic title was changed to professor of natural philosophy and mathematics; on December 4, 1810, he was elected Vice-Provost of the University of Pennsylvania. His resignation of both offices was accepted on August 9, 1813 by the Trustees who adopted a resolution thanking him "for his long and faithful services in this Seminary." In 1819 the University conferred on him the degree of Doctor of Laws (**67**).

The annual city directories (**68**) reveal that Robert Patterson was a member of the Select Council of Philadelphia during 1802–1805, and was its President for at least the last three of these years.

Robert Patterson was appointed fourth Director of the Mint by President Thomas Jefferson, January 17, 1806, and was succeeded by his son-in-law, Samuel Moore, an appointee of President James Monroe, July 15, 1824. During Patterson's directorship, the mint occupied a building erected for it in 1792 at 37 and 39 North Seventh Street, Philadelphia. This was the first building erected for public use by the federal government (**69**). Robert Patterson was president of the American Philosophical Society from January 1, 1819 until his death (**70**).

F(erdinand) R(udolph) Hassler, the first Superintendent of the United States Coast and Geodetic Survey, in his plan, dated January

5, 1816, for putting into operation that Survey, wrote concerning its work on triangulation (71): "Robert Patterson, Esq. Director of the Mint in Philadelphia, has, from the beginning, been appointed general superintendent of this work. In him the correspondence, and general communications relative to it, have been made to centre."

The author is deeply indebted to the Rev. Dr. Alexander Mackie, the present president of the Presbyterian Ministers' Fund, for data concerning the connection of the Pattersons with that corporation. In 1717 the Synod (of Philadelphia) organized the Fund for Pius Uses. On January 11, 1759, Thomas and Richard Penn, Proprietaries of Pennsylvania, granted it a charter as "The Corporation for Relief of Poor and Distressed Presbyterian Ministers and of the Poor and Distressed Widows and Children of Presbyterian Ministers." This corporation, the oldest life insurance company in the world, assumed its present name "Presbyterian Ministers' Fund" by decree of Court of Common Pleas No. 3 of Philadelphia on March 10, 1888. Robert Patterson became a member of this corporation in 1785, was elected its treasurer May 22, 1798, and was succeeded in that office by his son, Robert Maskell Patterson in May, 1824. The election of Robert Patterson as a member marked the introduction of modern actuarial service into American life insurance. He formulated the plan of agreement on October 20, 1792, between the corporation and its annual contributors. Robert Patterson was author of "A Treatise of Practical Arithmetic" in two parts, published in Pittsburgh in 1818 and 1819. Mackie states "Part II is of particular interest from the point of view of life insurance because of a thorough discussion of the mathematical principles involved in annuities."

A tablet in the entrance hallway of the Alison Building, the home of the Presbyterian Ministers' Fund, describes Robert Patterson as the author of the first table of life insurance premiums calculated by an American actuary.

While Robert Maskell Patterson was not a member of the Chemical Society of Philadelphia, he is here included since his activities largely duplicate those of his father, Robert Patterson.

Robert Maskell Patterson was born in Philadelphia, March 23, 1787, and died there September 5, 1854. He was educated at the University of Pennsylvania (A.B. 1804, A.M. 1807, M.D. 1808), then studied chemistry, medicine, natural philosophy and natural history in Paris and London from 1809 to 1812. While in France, he executed the duties of Consul General of the United States in Paris. Sketches of his life are given by Du Bois (64) and Kane (72).

He was an original member of The Franklin Institute, became a life member in 1825, was elected a Manager in 1825, 1826, 1827, 1838, 1839 and 1840 (73) and resigned that office in 1840 (74). He was the first chairman of the Committee of Inventions in 1825, and served as

chairman of its successor, the Committee on Science and the Arts from 1836 to 1839. He declined the presidency of the American Philosophical Society in 1845, but held that office from January 5, 1849 to January 7, 1853 (**70**). In the faculty of the University of Pennsylvania, he became professor of natural philosophy in the medical department in 1813, professor of natural philosophy and mathematics in the college department in 1814, and vice-provost of the University in the same year, resigning in 1828 to become professor of natural philosophy in the University of Virginia, where he remained until 1835. He was a Trustee of the University of Pennsylvania 1836–1854.

President Andrew Jackson appointed Robert M. Patterson the sixth Director of the Mint on May 26, 1835; he qualified on July 18, 1835, and remained in that office until July 1, 1851 when he resigned on account of ill health. Evans (**69**) states: "His term of office was marked by an entire revolution in the coinage, and the ready acceptance of those improvements which followed so rapidly upon the introduction of steam."[15] Du Bois (**64**) states that Patterson was responsible for the addition of three southern branches to the mint establishment. These branch mints, organized in 1838, were located at New Orleans, Louisiana; Charlotte, North Carolina; and Dahlonega, Georgia; they suspended operation in 1861; and those at Charlotte and Dahlonega were never reopened (**75**).

Robert M. Patterson was elected a member of the corporation, now known as the Presbyterian Ministers' Fund, in 1816, and served as its treasurer from May, 1824 to December 30, 1828, and from May 20, 1836 to May 21, 1852, when he resigned on account of "feebleness of his health." He was a director of the Pennsylvania Company for Insurances on Lives and Granting Annuities (known since September 30, 1955 as the First Pennsylvania Banking and Trust Company) 1820–1822 and 1842–1853, and was its president 1822–1826 (**76**).

As an item in the history of science in Philadelphia, mention should be made of Samuel Moore, son-in-law of Robert Patterson and fifth Director of the Mint, for, during his term of office, the second building of the mint was erected in Philadelphia, facing on Chestnut Street, and extending northward along the west side of Juniper Street to South Penn Square; the site is now occupied by the Widener Building. The corner stone was laid July 4, 1829, the building used from 1833 to 1901.

Samuel Moore was born in Cumberland County, New Jersey, February 8, 1774, and died in Philadelphia, February 18, 1861. The records in the Alumni Records Office of the University of Penn-

[15] The Franklin Institute Museum contains a steam coining press, designed by Franklin Peale, constructed by Merrick, Agnew and Tyler of Philadelphia, and installed in the Philadelphia Mint in 1836. All four men were members of the Institute. In 1840, on the recommendation of the Institute, the City of Philadelphia awarded to Peale the John Scott Medal and Premium for these presses.

sylvania show his graduation (A.B.) from the University of the State of Pennsylvania in 1792, award of the A.M. degree to him by the University of Pennsylvania in 1795, and his attendance at its medical school during the session of 1794–1795. He was a tutor in the University 1792–1794.

Moore was a member of the United States House of Representatives from Pennsylvania from October 13, 1818 to May 20, 1822, and was appointed Director of the Mint by President James Monroe on July 15, 1824, and served until 1835. He also engaged in manufacturing and mining (**64, 69, 77**).

James H. Robins, who delivered the address at the celebration of the 125th anniversary of the founding of The Franklin Institute (**78**) is a grandson of Robert Maskell Patterson and a great-grandson of Robert Patterson, and has been a member of the Board of Managers of the Institute since 1942.

CHAPMAN, HAYS AND CAREY

Nathaniel Chapman was elected a member of The Franklin Institute on October 13, 1831 (**79**). He was nominated by Isaac Hays, who was an original member of the Institute, became a life member in 1840, was elected Corresponding Secretary yearly from 1828 to 1839 both inclusive, and was elected a Manager in 1840 and 1841 (**80**). Chapman had been Hays' preceptor. Hays was an alumnus of the University of Pennsylvania (A.B. 1816, A.M. 1819, M.D. 1820), was one of the first group of surgeons elected to the staff of Wills Hospital in 1834 (**81**), author of the original Code of Medical Ethics of the American Medical Association, and succeeded Chapman as editor of *The American Journal of the Medical Sciences*. Hays' life was spent in Philadelphia from birth on July 5, 1796 to death on April 12, 1879 (**82**).

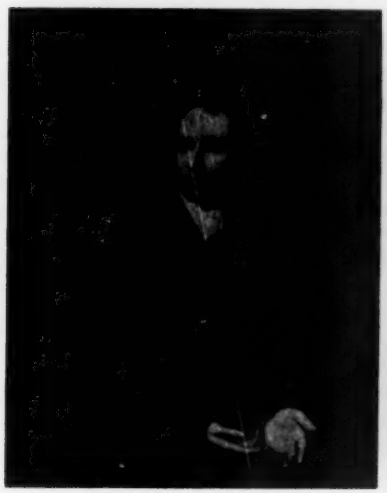
Nathaniel Chapman (**83**) was born in Fairfax County, Virginia, in 1778[16] and died in Philadelphia on July 1, 1853. Prior to matriculation as a student of medicine, he had as his preceptor Elisha Cullen Dick of Alexandria, Virginia (M.B. 1782 University of the State of Pennsylvania) who was one of George Washington's physicians during his last illness. Chapman graduated as doctor of medicine from the University of Pennsylvania in 1800; his thesis was entitled "On the Canine State of Fever," that is, rabies or hydrophobia. While Chapman also studied abroad, especially in London and Edinburgh, the statement, sometimes made, that he also graduated in medicine at Edinburgh apparently is incorrect, for his name does not appear in the list of its graduates in medicine (**84**) or in the list of its American graduates in medicine compiled by Samuel Lewis (**85**). At the University of Pennsylvania, Chapman was successively lecturer on obstetrics (1810–1813), professor of materia medica (August 3, 1813 to March 5,

[16] S. W. Butler, in a chapter in Henry Simpson's "Lives of Eminent Philadelphians now Deceased," published in 1859, states Chapman was born May 28, 1780.

1816), then professor of the theory and practice of medicine, institutes, and clinical medicine; in 1827 Samuel Jackson became his assistant to give the lectures on the institutes of medicine; Jackson was elected professor of that subject on October 6, 1835; Chapman remained professor of the theory and practice of medicine and clinical medicine until his resignation in the spring of 1850.

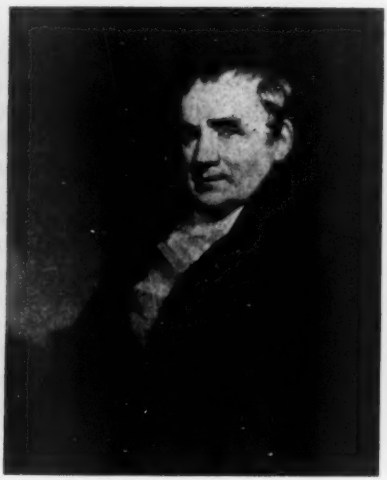
Chapman was president of the American Philosophical Society from January 2, 1846 to January 5, 1849 (**70**). He was president, from 1816 to 1820, of The Philadelphia Medical Society, an incorporated body which existed from 1789 to 1868; its history has been published by Radbill (**86**). Upon the organization of the American Medical Association in 1847, Chapman served as its first president (**87**). Chapman was elected an Honorary Member of the Philadelphia College of Pharmacy in 1824 (**88**), and became a fellow of the College of Physicians in 1807.

In 1820 the firm of M. Carey & Son, founded in 1785 by Mathew Carey and still existing as Lea & Febiger, began the publication of a periodical, the *Philadelphia Journal of the Medical and Physical Sciences*



NATHANIEL CHAPMAN

Portrait* by Thomas Sully in the College of Physicians of Philadelphia



MATHEW CAREY

From the engraving by Samuel Sartain of the portrait painted by John Neagle in 1825 and now owned by Carey's great-great-great grandson, H. Lea Hudson. Courtesy of Lea & Febiger.

* This portrait was presented to the College of Physicians by Mrs. Henry Cadwalader Chapman in 1909 in memory of her husband, who was the grandson of Nathaniel Chapman, lived 1845–1909, served as professor of the institutes of medicine and medical jurisprudence in Jefferson Medical College 1880–1909, became a fellow of the College of Physicians in 1880, and a member of The Franklin Institute, in 1881.

with Nathaniel Chapman as its editor. Mathew Carey was still an active member of the firm, not retiring until 1824. Chapman remained the editor until 1827. Isaac Hays became associated with Chapman in an editorial capacity in 1826, assumed the editorship in 1827, retained it until 1869, and thereafter until his death in 1879 shared it with his son, I. Minis Hays. In 1827 the name of the periodical was changed to its present title, *The American Journal of the Medical Sciences*. It is the oldest American medical periodical and, with a single exception, the oldest medical periodical in the English language with a continuous existence, and is still published by the firm which founded it (**82, 89**).

Mathew Carey was a living link between Benjamin Franklin and The Franklin Institute. Born in Dublin in 1759, and trained as a printer, he became a political refugee in Paris at the age of twenty. There he acquired the friendship of Franklin and of the Marquis de La Fayette, and assisted Franklin in his print-shop at Passy in printing the dispatches from America. He returned to Ireland, but again became a political refugee, and landed in Philadelphia on November 15, 1784, with only a few guineas in his pocket. La Fayette, then a guest of Washington at Mount Vernon, learned from a fellow-passenger of Carey of the latter's arrival, and sent him a check for four hundred dollars. With this capital Carey began the publication of a daily newspaper, and later became a publisher of journals and books. When La Fayette visited the United States in 1824, Carey repaid to him the benefaction of four hundred dollars. Carey died in 1839 (**89**).

Mathew Carey, late (that is, retired) bookseller and printer, was an original member of The Franklin Institute. He was elected a vice-president in 1824, was reelected annually four times, became chairman of the Board of Managers in August, 1824, and resigned that office in November, 1825. He was a member of the Committee to draft a memorial to the legislature for a charter, of the committee which drafted the original by-laws of the Board of Managers, and of the committees on publication, lectures, finance, and library, and was the first chairman of the last named committee (**90, 91**).

Reference has been made to Carey's "Short Account of the Malignant Fever, Lately Prevalent in Philadelphia" (**10**) in connection with the death of John Penington.[17] This brochure is an account of the yellow fever epidemic of 1793. Carey was a member of the "Committee for relieving the sick and distressed, appointed by a meeting of the

[17] See footnote 3. Carey's brochure was published by him in Philadelphia in four editions in 1793, and in two issues of an improved fourth edition in 1794. It was also published in German (2 editions), French (4 editions), and Dutch (1 edition), as well as reprinted in London (92). The Philadelphia German edition of 1794 was printed by Samuel Saur, the Philadelphia French edition of 1794 by Parent; a copy of each is in the library of the College of Physicians of Philadelphia. A "fifth edition, improved" appeared as the first article in a volume of "Miscellaneous Essays—By M. Carey" printed in Philadelphia in 1830 for Carey and Hart by Clark and Raser.

citizens of Philadelphia, summoned by advertisement in the public papers, Sept. 13, 1793." Four members of this committee died of yellow fever during the epidemic. Of the score of men associated with Carey on this committee, probably the best known today was a native of France; born near Bordeaux, May 20, 1750, he arrived in Philadelphia in 1778, and died here, December 26, 1831. In his will he described himself as "mariner and merchant"; he may also be designated patriot and philanthropist; patriot for his part in financing the War of 1812, philanthropist for his founding of Girard College. His name was Stephen Girard (93). The work of the committee in the panic-stricken, partially deserted city is vividly described by Carey in his brochure (10).[18]

REMBRANDT PEALE

Rembrandt Peale, the son of Charles Willson Peale, was elected a member of The Franklin Institute in 1838. He is not included in Miles' list of members of the Chemical Society of Philadelphia (16) but attended the Chemical School of the University of Pennsylvania about 1795. Sellers (94) states that Rembrandt Peale had enrolled himself in the lectures of Woodhouse on chemistry in the medical school of the University "that he might have a full understanding of the chemical qualities of pigments, and avoid his father's unhappy experience with fading colors." He was an eminent artist and author, and was professor of drawing and writing in the Central High School of Philadelphia from 1840 to 1844. His two treatises on the mammoth report pioneer research in American paleontology conducted by his father and himself in the valley of the Hudson River in 1801. The Franklin Institute Library contains a copy of the later of these treatises (95).

The members of the Chemical Society of Philadelphia labored to increase knowledge in the field of science, and to apply that knowledge for the common-weal. The same purpose gave rise to The Franklin Institute, and has actuated it during its entire existence.

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[18] A more elaborate account of this epidemic has recently been published by Powell (92).

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THE UNDETERMINED CONSTANT IN RELATIVE-VELOCITY ELECTRODYNAMICS

BY

RODNEY D. DRIVER [1]

In the October issue of the JOURNAL, P. Moon and D. E. Spencer (1)[2] discuss an undetermined constant appearing in the equation for the force between moving charges. They conclude that this constant, C, must be zero. However, closer examination of the calculation which led to this conclusion reveals an error.

The force on a charge in the plane of a rectangular circuit and having a velocity perpendicular to that plane is obtained by integrating

$$\vec{dF} = \vec{a}_n \frac{Q_2|I_1|Cv_2}{4\pi\epsilon c^2} \frac{ds_1}{r^2} \cos\theta_1$$

around the circuit. The result, however, is $\Delta\vec{F} = 0$ (regardless of the value of C) rather than Moon and Spencer's Eq. 17. Therefore this does not determine C. In carrying out the integration one must remember that the circuit has finite dimensions, Δx and Δy, so the integral must be computed exactly with the proper limits of integration for each segment of the circuit.

The following proof shows that C drops out of all calculations for the force on a moving charge due to a closed circuit carrying constant current. Re-writing, in vector notation, Moon and Spencer's Eq. 12 for the force on Q_2 moving with constant velocity $\vec{v}_2$ relative to circuit element $|I_1|\vec{ds}_1$ gives

$$\vec{dF}_2 = \frac{Q_2|I_1|}{4\pi\epsilon c^2} \left\{ \left[2\frac{\vec{r}}{r^3}(\vec{v}_2\cdot\vec{ds}_1) - 3\frac{\vec{r}}{r^5}(\vec{v}_2\cdot\vec{r})(\vec{r}\cdot\vec{ds}_1) \right] + C\left[-3\frac{\vec{r}}{r^5}(\vec{v}_2\cdot\vec{r})(\vec{r}\cdot\vec{ds}_1) + \frac{\vec{r}}{r^3}(\vec{v}_2\cdot\vec{ds}_1) + \frac{\vec{ds}_1}{r^3}(\vec{v}_2\cdot\vec{r}) + \frac{\vec{v}_2}{r^3}(\vec{ds}_1\cdot\vec{r}) \right] \right\}. \quad (1)$$

The finite drift velocity, v_1, of the electrons in the wire is neglected as compared to v_2. Consider the last bracket in Eq. 1, that is, all the terms having C as a coefficient. When integrating around a circuit, $\vec{ds}_1 = \vec{dr}$

[1] Institute of Technology, University of Minnesota, Minneapolis, Minn.

[2] The boldface numbers in parentheses refer to the references appended to this paper.

therefore

$$\frac{\vec{v}_2}{r^3}(\vec{ds}_1\cdot\vec{r}) = -\,d\left(\frac{\vec{v}_2}{r}\right) \tag{2}$$

and

$$-\,3\frac{\vec{r}}{r^5}(\vec{v}_2\cdot\vec{r})(\vec{r}\cdot\vec{ds}_1) + \frac{\vec{r}}{r^3}(\vec{v}_2\cdot\vec{ds}_1) + \frac{\vec{ds}_1}{r^3}(\vec{v}_2\cdot\vec{r}) = d\left[\frac{\vec{r}(\vec{v}_2\cdot\vec{r})}{r^3}\right].$$

Thus C appears as the coefficient of a total differential and hence drops out when $d\vec{F}_2$ is integrated around any closed circuit.

The total force on Q_2 results from integrating the remaining terms (the first bracket of Eq. 1) around the circuit. In so doing one can, for convenience, subtract from these terms the second total differential of Eq. 2 and obtain

$$\vec{F}_2 = \oint d\vec{F}_2 = \frac{Q_2|I_1|}{4\pi\epsilon c^2}\oint\left[\frac{\vec{r}(\vec{v}_2\cdot\vec{ds}_1) - (\vec{v}_2\cdot\vec{r})\vec{ds}_1}{r^3}\right]$$

$$= \frac{Q_2\mu|I_1|}{4\pi}\oint\frac{\vec{v}_2\times(\vec{r}\times\vec{ds}_1)}{r^3} = Q_2\vec{v}_2\times\vec{B} \tag{3}$$

where $\vec{B}$ is the conventional magnetic field. Hence it is proved that Moon and Spencer's Eq. 3 for the force between moving charges provides the correct force on a charge due to a constant current in a *general closed circuit regardless of the value of C.*

Another part of the article which bears further study is section 9. The calculations given there do not lead unambiguously to the conclusion that the mass of an electron is independent of its velocity. They show that the Kaufmann-Bucherer experiment can be explained on the basis of a constant mass and a variant electric force. However, an implicit assumption is made that the force due to a magnetic field, Eq. 3 above, holds for high velocities. Since the force laws discussed are only derived for low speeds, the addition of higher order velocity terms in the force equation might well provide a change in Eq. 3 for large velocities.

If the mass of an electron were assumed invariant it turns out that one could evaluate C by means of another "relativity experiment" as follows. An electron falling through a potential, V, is assumed to gain a velocity, v, given by

$$Q_2V = m_0c^2\{[1 - (v/c)^2]^{-\frac{1}{2}} - 1\}. \tag{4}$$

This result was verified for low velocities by Perry and Chaffee (2). Consider the electron as being accelerated in the z-direction by a uniform electric field between large parallel plates. Then

$$Q_2E = d/dz(Q_2V) = m_0v dv/dz[1 - (v/c)^2]^{-\frac{1}{2}} = m_0\ddot{z}[1 - (v/c)^2]^{-\frac{1}{2}}. \tag{5}$$

Now if mass is considered constant the force must be

$$F_z = m_0 \ddot{z} = Q_2 E[1 - (v/c)^2]^{\frac{1}{2}} \doteq Q_2 E[1 - \tfrac{1}{2}(v/c)^2]. \tag{6}$$

Making a calculation similar to that of reference (1) for the force on a charge moving in the z-direction between two infinite parallel plates gives

$$F_z = Q_2 E[1 + (\tfrac{1}{2} + C)(v/c)^2]. \tag{7}$$

If mass were constant this would have to agree with Eq. 6, hence C would have to be -2.

However, the assumption of constant mass leads to trouble in explaining high electron energies. If the mass of an electron were constant its kinetic energy would be $\frac{1}{2}mv^2$. If, in addition, its maximum speed were c then its greatest possible kinetic energy would be $\frac{1}{2}mc^2 = 255{,}000$ electron volts. There is evidence that electrons can have much higher energies. Note that the value $C = -\frac{1}{2}$ would reduce Eq. 7 to the classical result and allow the concept of a variable mass. It seems, then, that C remains undetermined.

It is also possible to give more general acceleration terms for the force equation than presented by Moon and Spencer (3). I have been able to prove that the most general force equation for low velocities and accelerations and assuming Galilean relativity is

$$\begin{aligned}\vec{F}_2 = -\frac{Q_1 Q_2}{4\pi\epsilon}\Bigg[& \frac{\hat{r}}{r^3} + \frac{1}{2}(C+2)\frac{\hat{r}v^2}{c^2 r^3} - \frac{3}{2}(C+1)\frac{\hat{r}(\vec{v}\cdot\hat{r})^2}{c^2 r^3} \\ & + C\frac{\vec{v}(\vec{v}\cdot\hat{r})}{c^2 r^3} - (H+1)\frac{\hat{r}[(k\vec{g}_2 - \vec{g}_1)\cdot\hat{r}]}{c^2 r^3} + H\frac{k\vec{g}_2 - \vec{g}_1}{c^2 r}\Bigg],\end{aligned} \tag{8}$$

where $\vec{g}_1$ and $\vec{g}_2$ are the accelerations of Q_1 and Q_2 and H and k are two more undetermined constants. Regardless of the values of H and k, these acceleration terms give correctly Faraday's law of induction due to time-changing currents. If $k = 1$ the force depends only on the acceleration of Q_2 relative to Q_1, while $k = 0$ gives a force independent of the acceleration of Q_2 (as in Ritz's theory). Equation 8 contains, as special cases, the equations of Gauss, Weber, Riemann, Ritz, and Warburton. It also includes Moon and Spencer's Eq. 25, ref. 3 except for their term allowing for time-variation of Q_1.

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DISCUSSION

BY

PARRY MOON [1] AND DOMINA EBERLE SPENCER [2]

We are grateful to Mr. Driver for pointing out the error in our Eq. 17. The mistake was discovered also by F. W. Warburton and independently by G. J. Baker.

It should be emphasized, however, that Driver's work does not in any way invalidate the other equations of our paper nor does it alter our conclusions (1) to (5) of p. 310. The paper consisted of the derivation of general equations (containing C) and the consideration of possible experiments that might evaluate C. Among the possibilities were experiments on the force between: (*a*) current elements; (*b*) complete circuits; (*c*) charged particle and circuit; and (*d*) two charged particles.

If the force between current elements is to behave as assumed by Ampère, then C must be zero (p. 298). On the other hand, the force between complete circuits is always independent of C; so *no experiment on complete circuits can ever evaluate* C. The same conclusion applies to a complete circuit and a charged particle. In the remaining case (*d*), the Coulomb force is so large in comparison with the Ampère force that a determination of C by this means seems highly unlikely.

Our aim throughout the development of the new electrodynamics has been to establish a single equation that will cover all of macroscopic electrodynamics (JOUR. FRANKLIN INST., Vol. 257, Eq. 25, p. 381). No claim has been made that this general equation is unique. In fact, such a claim can hardly be made for any equation of physics: Further experimental data may always show that an established "law of nature" is only an approximation. Thus our aim is a pragmatic one—we present the simplest possible equation (Eq. 25, p. 381; $C = 0$) that will fit the experimental facts. If this equation is useful, let us use it. If further research should ever show that better results are obtained with some other value of C, let us then make the necessary change. But to burden a formulation with an unnecessary constant, whose effect cannot be detected by any known experiment, is contrary to Occam's principle. We continue, therefore, to let $C = 0$ as in our previous papers; and we reiterate our statement (p. 295) that "though the criticism is justified, it has no practical significance."

Driver's Eq. 8 is a modification of the Warburton equation. Irrespective of its reputed generality, this Eq. 8, like Warburton's, appears to be incapable of handling even the simple dipole antenna. As shown previously (JOUR. FRANKLIN INST., Vol. 258, p. 395), the Warburton equation gives the wrong magnitude and even the wrong direc-

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[2] Department of Mathematics, University of Connecticut, Storrs, Conn.

tion for the field. Similar results are obtained with Driver's modification, regardless of the values of his constants C, H, and k. Obviously, if the equation fails in this example, it cannot be depended on as a basis for electrodynamics.

In his Eqs. 4 to 7, Driver claims to have found a method for evaluating C. The derivation is a strange mixture of Maxwellian ideas and the new electrodynamics. Two errors are made: the assumption that the electrodynamic field can be expressed in terms of a scalar potential, and the neglect of acceleration. Both Ampère and Weber forces require a *vector* potential (See forthcoming papers, "Field Theory of the New Electrodynamics," "Maxwell's Theory and the New Electrodynamics") and cannot be formulated in terms of a scalar potential. Also, since the electrons are accelerated, the acceleration term of our Eq. 25 is important. In the new electrodynamics, *the electron volt is meaningless*. Thus C cannot be determined from the Perry-Chaffee results.

The next question is with respect to electrons at high velocity. Our analysis of the Kaufmann effect was not designed to *prove* that mass is invariant. We *postulated* that mass is invariant and showed that, on this basis, the new electrodynamics agrees with experiment. Thus the postulate of constant mass is a tenable one,[3] and one that we regard as highly desirable. Obviously, there is nothing unique about this formulation: a variable mass is another possibility. As Driver remarks, one obstacle to the invariant-mass formulation is the experimental fact that high-velocity electrons seem to have greater kinetic energy than can be accounted for on the basis of $\frac{1}{2}m_0c^2$. But could this not mean merely that the electrons are traveling at more than the velocity of light[3] or that the low-velocity expression for kinetic energy is inapplicable to high-velocity electrons?

The new electrodynamics (with Galilean relativity, invariant mass, and $C = 0$) predicts correctly a wide range of electrodynamic phenomena and eliminates ambiguities that arise in classical electromagnetism. The new formulation abolishes fictitious electric and magnetic fields and presents a picture that is more in keeping with traditional modes of thought than is Einstein's theory. Further work will be necessary to determine how well our formulation fits into the ramifications of modern physics.

[3] Note that the new electrodynamics employs Galilean relativity, not Einstein's relativity; so the Lorentz transformation is not applicable and velocities are not necessarily limited.

Copper-Clad Laminates for Printed Circuitry.—Using a special bonding technique, International Resistance Company, Philadelphia, has succeeded in cladding a non-adherent polymer, fluorocarbon plastic, with copper. The resulting new laminate, in which no resin adhesive is used, features very low cold flow, zero water absorption, excellent machineability and a water-repellent surface. Also, it is unaffected by acids, alkalies, or common organic solvents. Fluorocarbon plastic is a thermoplastic material, and is inherently less rigid than thermosets—especially in thin sections. This copper-clad laminate is especially recommended for use under severe temperature, moisture, and electrical conditions.

Permanent-Magnet Thickness Gage.—A hand-held thickness gage, which operates on a magnetic principle and requires no power, has been developed by General Electric's Instrument Department in Lynn, Mass. The new Permanent-Magnet (PM) Thickness Gage is designed for quick, accurate, non-destructive measurement of the thickness of nonmagnetic materials bonded to smooth iron or steel. The gage will also measure the thickness of nonmagnetic materials which can be placed over a magnetic reference plate. Typical materials which can be measured are paint coatings, platings, enamels and sheet materials such as plastics, paper and mica.

The small, portable gage consists of a double range scale (high scale from 0.001 to 0.060 in. and low scale from 0.000 to 0.007 in.), range changing slider, calibration adjuster, adjuster, adjustable limit pointers, and reference thickness standards.

A "go-not go" feature is built into the gage to help the user maintain quality control on surface coating thicknesses. After the instrument is calibrated and adjusted for the specific range limits, the user need only note if the null pointer stays between the red upper limit and red lower limit pointers to maintain the desired quality. When using the "go-not go" feature, the gage is calibrated for the nominal value of the thickness to be measured. Upper and lower limits are set to correspond with the maximum and minimum thicknesses and coatings can then be checked on a "go-not go" basis.

The instrument uses an internal alnico magnet which provides flux to the contact feet. A variable air gap in the magnetic circuit—introduced by the variable thickness of the film on the backing material—causes flux changes in the circuit. The thicker the film the more flux will leak between two iron legs located between the magnet and the contact feet. A G-E gaussmeter-type movement measures this internal leakage flux.

Accuracy of the PM Thickness Gage is +5 to +10 per cent within 50 per cent of the calibration point and is capable of taking readings in any position, making it ideal for spot checks on a production line.

Other features of the new gage include the ability to measure both conducting and non-conducting coatings, the wear-resistant probes which are chrome-plated, and greater readability at the lower end of the dual range scale.

A leather carrying case with removable straps and a belt loop is furnished with the instrument along with four thickness standards. Ten extra standards are available, ranging from 0.0005 in. to 0.060 in.

NUCLEAR ENERGY NEWS

TWO NUCLEAR POWER PLANTS FOR CALIFORNIA

California will be the site of two small nuclear power plants, which will be among the first to furnish electricity for distribution by public utility companies. Each will include an experimental reactor intended to give design information for a much larger one elsewhere.

One of these reactors is the sodium graphite reactor being built for the Atomic Energy Commission by the Atomics International Division of North American Aviation, Inc., as part of the Commission's five-year reactor development program. As previously announced (see this JOURNAL, Vol. 261, p. 239), the surplus heat from this reactor is to be used to generate steam.

The Atomic Energy Commission has authorized Atomics International to enter into an agreement with the Southern California Edison Company for the addition of electric generating equipment to the reactor. Southern California Edison is to design, construct, and operate, at no cost to the government, a heat exchanger and turbogenerator with an electrical capacity of about 7500 kilowatts. Edison's investment in this equipment will be over $1,000,000; and Atomics International is contributing $2,500,000 to the reactor project itself.

The electricity from this reactor will be fed over Edison lines to consumers in the Santa Susana area (northwest of Los Angeles) in the summer of 1956. The experience from this operation will be applied to the design of a full-sized control station plant, producing 75,000 kilowatts of electrical power, which Atomics International is to build for the Consumers Public Power District of Nebraska, following completion of negotiations that have been authorized by the AEC.

The second California reactor was announced by the General Electric Company on March 1. It has entered into an agreement with the Pacific Gas and Electric Company for the operation of a nuclear power plant in the Livermore-Pleasanton area, 40 miles southeast of San Francisco. The announcement emphasized that this reactor, which is to be completed during 1957, will be the first to be financed entirely by private capital. It is expected to cost between $3- and $4-million.

This reactor will be a pilot plant for G. E.'s innovation of a dual-cycle boiling water reactor. (See this JOURNAL, Vol. 260, p. 132.) Its initial generating capacity is to be 5000 kilowatts and its ultimate capacity 10,000 kilowatts. This experimental reactor will provide information of extreme value in the development of the large dual-

cycle reactor that G. E. is to build for the 180,000 kilowatt all-nuclear Dreseden power plant of the Commonwealth Edison Company near Chicago. This plant is expected to go into operation during 1960.

The Livermore reactor will be located at the General Electric Company's new atomic laboratory, which is being built for the development of the peacetime uses of atomic energy. This laboratory will be organized as a component of the company's Atomic Power Equipment Department, which is being moved to San Jose, California. The laboratory is to occupy a 1658-acre site in Alameda County.

FIRST EXPORT OF HEAVY WATER

Approval of the sale of 129 tons of heavy water to six nations for assistance in their peacetime applications of atomic energy was announced in mid-March by the U. S. Atomic Energy Commission. Sixteen tons of the material have been shipped abroad. The heavy water will be used as a moderator in reactors.

The total amounts approved for sale are as follows: United Kingdom —50 tons, France—30, India—21, Australia—11, Italy—10 and Switzerland—up to 7, with 2 tons to be delivered by August, 1957.

The initial consignments of 11 tons to Great Britain and 5 to France were manufactured at the Commission's plant at Dana, Indiana. Heavy water also is produced at its facilities in South Carolina. All sales are at the price of $28 per pound announced August 8, 1955.

Included in the 129-ton total was an additional 11 tons for the Government of India. An original order of 10 tons for India, announced February 12, 1955, was the first to be approved for this special reactor material under the President's atoms-for-peace program.

The 21 tons will be used by the Government of India in a research reactor which the Government of Canada has announced it plans to give India under the Colombo Plan.

Britain will use the material in several of its civilian research reactors. The Swiss order is to go to Reactor, Ltd., the private group which carries on nuclear research in Switzerland and operates the pool type research reactor purchased from the United States at the close of the atoms-for-peace Conference in Geneva last August.

TWO ACCELERATOR PROJECTS FOR AEC

The U. S. Atomic Energy Commission has authorized the design and development of high-energy particle accelerators by both Midwestern Universities Research Association and the Argonne National Laboratory at Lemont, Illinois.

Argonne National Laboratory, operated for the AEC by the University of Chicago, is one of the Commission's major research and development facilities, and is devoted to reactor development and basic research. The scope of the laboratory's program includes research with high-

energy accelerators. Facilities at the laboratory are available for the use of university scientists.

The midwestern Universities Research Association has the following universities as associated members: University of Chicago, University of Illinois, University of Indiana, University of Iowa, Iowa State College, University of Michigan, Michigan State University, University of Minnesota, Northwestern University, Notre Dame University, Ohio State University, Purdue University, Washington University (St. Louis, Mo.), and University of Wisconsin.

A five-man planning committee for the project has been named by the institutions. Frederick Hovde, President of Purdue University, is Chairman, and members are Virgil Hancher, President of the University of Iowa; Dr. Alfred W. Peterson, Vice-President for Business and Finance, University of Wisconsin, Mr. Herbert O. Farber, Comptroller, University of Illinois; and Dr. John H. Williams, Professor of Physics, University of Minnesota.

Subject to Congressional authorization and appropriation, and to the Commission's approval of detailed plans, scope and feasibility of the machines, the Commission will support the design, development, construction and operation of both accelerators.

Recent discoveries made with existing particle accelerators, such as the Bevatron at the University of California Radiation Laboratory and the Cosmotron at Brookhaven National Laboratory, have opened promising new fields of research.

The Bevatron, which accelerates particles to energies of more than six billion electron volts, is the most powerful particle accelerator known to exist today. Several more powerful machines are under construction —one in Switzerland, one in the United States and one in the U.S.S.R. The U. S. machine, which will produce particles with energies of about 30 billion electron volts, will be the largest in the world when its construction is completed at Brookhaven National Laboratory in about 1960.

It is hoped that the midwest university scientists will develop a machine that will be the finest and most powerful in the world at the time of its completion, and that the accelerator will aid in maintaining United States leadership in nuclear and high-energy physics in subsequent years. Features of the design, including the voltage and beam intensity, have not been definitely determined as yet.

BERYLLIUM PRODUCTION BY PRIVATE INDUSTRY

Approximately 75 representatives of 47 industrial concerns toured the Luckey, Ohio Government-owned beryllium manufacturing plant on March 5.

These industrial organizations responded to the January invitation made by the Atomic Energy Commission to supply reactor grade

beryllium. (See this JOURNAL, Vol. 261, p. 355.) Their representatives visited the Luckey plant to orient themselves with the problems which may be encountered in the production of vacuum cast billet metal from beryllium ore.

NEW PROCEDURES FOR ISOTOPE DISTRIBUTION

Simplified procedures for the domestic and foreign distribution of stable (non-radioactive) isotopes and rare earths produced by the U. S. Atomic Energy Commission have been announced. Stable isotopes have had important applications in basic research in such fields as biology, medicine, chemistry, and metallurgy. Rare earths also are of research interest.

Under the revised procedures, neither domestic nor foreign applicants will be required to file and obtain Commission approval of applications before purchasing the materials. Requests and purchase orders will be handled directly between the user and the AEC facility supplying the materials. Electromagnetically-concentrated stable isotopes will be available for sale to domestic users; they were previously available only on a loan basis. Reports of results of experiments using the materials will not be required from either U. S. or foreign applicants.

The export of deuterium or deuterium compounds to any country listed as a Subgroup A (Soviet Bloc) country in Section 371.3 of the comprehensive Export Schedule of the U. S. Department of Commerce is prohibited. Export of deuterium or deuterium compounds to any other country requires a special export license from the Department of Commerce. Prior approval of the Atomic Energy Commission must be obtained for sale of any other stable isotope to a person in a Soviet Bloc country.

The Commission will establish annual or special quotas of the total quantity of each item to be distributed and the maximum amount which will be available to any one person, firm or institution without special Commission approval. Samples of rare and expensive items may be loaned, provided they will not be diluted or contaminated during use.

Sale prices and charges for loan of the materials will be established by the Commission. The Commission will distribute only those materials which are not available commercially, unless the requestor certifies that the commercial product does not meet purity or quantity specifications required for his research.

Stable isotopes currently available for distribution include Deuterium, Helium-3, Boron 10 and 11, Oxygen 18, Argon 38, and the electromagnetically-concentrated isotopes of approximately 80 elements. The rare earths included in the distribution program are those in the Lanthanide Series: elements 58 to 71 inclusive. Other items may be added to the list as they become available.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS

RAPID DETERMINATION OF LENS DISTORTION

A study by the National Bureau of Standards has shown that the distortion in the image produced by a projection lens can be readily calculated as a linear function of the magnification. A. A. Magill of the Bureau's optical instruments laboratory has developed a simple equation which expresses the distortion at any magnification in terms of the magnification and of two previously measured distortions.[1] This equation should be particularly valuable in the field of photogrammetry, where high precision is required in order to produce accurate maps from aerial photographs.

The distortion produced by a lens when used for copying or projection varies with the magnification at which it is used. It has been customary, when high precision work is involved, to measure distortion in the laboratory for each object-to-image ratio employed. However, when the equation developed at NBS is used, distortion need be measured at only two magnifications.

The two distortions used are those obtained with parallel light incident, in turn, on the front and on the back of the lens. These distortion values not only require the simplest experimental setup but also have special significance in being determined at the limits of real image formation.

Specifically, if D_0 represents the distortion obtained with parallel light incident on one side of the lens (zero magnification) and D_∞ the distortion obtained with parallel light incident on the other, then the distortion D_m at any finite magnification is given by $D_m = D_0 - mD_\infty$.

The definition of distortion used for the Bureau's equation is simply the lateral displacement of the image from its theoretical distortion-free position. A relation between distortion and magnification previously developed by E. Wandersleb[2] is hyperbolic since he defines distortion as the ratio of the displacement of the image to the distance between the distortion-free position and the axis of the lens.

The Bureau has verified the linear equation for three commonly used types of symmetrical objectives at relative apertures of f/22. It was concluded that under certain limitations the same type of computation may be carried out with other kinds of lenses.

[1] For further technical details, see "Variation in Distortion with Magnification," by A. A. Magill, *J. Research NBS*, Vol. 54, p. 135 (1955) RP 2574.

[2] E. Wandersleb, "Uber die Verzeichnungs Fehler Photographischer Objectiv," *Z. Instrumentenk*, Vol. 27, pp. 33–37, 75–85 (1907). The equation is also used in many optical texts.

TEMPERATURE CONTROL FOR MIXING RUBBER COMPOUNDS

The National Bureau of Standards has developed special temperature-controlled steel rolls for laboratory mixing of rubber compounds. Designed by F. L. Roth, G. E. Decker, and R. D. Stiehler of the Bureau's rubber laboratory, the rolls use an automatic control system[1] based on a thermocouple sensing element to maintain constant roll surface temperature. Development of the rolls was sponsored by the Federal Facilities Corporation, Office of Synthetic Rubber, in connection with the Government synthetic rubber program.

Small-scale mills are widely used by testing laboratories to mix rubber compounds. However, their limited size (6 × 12 in.) makes temperature control difficult; this has been disadvantageous because the properties of the rubber compound are appreciably affected by mixing temperatures. For example, the Mooney viscosity of GR-S[2] compounds increases as the roll surface temperature increases. Also, the tensile stress *versus* elongation curves of cured vulcanizates show that stiffness increases and elongation at failure decreases with increasing roll temperature.

The effects of roll temperatures are recognized in the Government specifications for synthetic rubbers and in ASTM standards, both of which prescribe limits for the temperatures of the mill roll surfaces during mixing. Even though these limits permit a range of 18 or 20 deg. F. in the surface temperature, it is difficult to maintain this temperature control because the rate of heat transfer through the conventional thick-walled roll is too slow.

In recent years it has become increasingly clear that the mixing temperatures of rubber compounds must be controlled if reproducible values for their properties are to be obtained. The Bureau therefore made an intensive study of roll temperature control which resulted in the present roll design.

Laboratory mill rolls are used in pairs; the space between them can be adjusted to control the thickness of the rubber. The rolls turn at different speeds and thus produce a shearing action on the rubber compound. This action is used in introducing into the rubber the various ingredients, such as carbon black and sulfur. Temperature control is especially difficult at the time of the addition of ingredients during mixing.

Most rolls are constructed with a central cavity $1\frac{1}{4}$ to 2 in. in diameter. Cooling or heating of the roll is accomplished by spraying water or steam against the walls of the cavity. Since there are two or more inches of steel between the cavity walls and the outer surface of the

[1] For further technical details, see "Temperature Control During Mixing of Rubber Compounds," by F. L. Roth, G. E. Decker, and R. D. Stiehler, *Rubber World*, Vol. 132, p. 483 (1955).

[2] GR-S is the synthetic rubber made by copolymerizing butadiene and styrene.

roll, the rate of heat transfer is too slow to control the temperature within a few degrees, particularly when the heat generated by the rubber compound during mixing varies.

The Bureau investigated a special roll in which the diameter of the cavity was increased to four inches, leaving only one inch of metal in the walls. This roll had an increase rate of heat transfer but did not control temperature as precisely as desired. Another mill roll, in which the water or steam travels through spiral cavities near the roll surface, had an improved rate of heat transfer. When an automatic controller was used with each roll, the spiral type could control surface temperatures within a range of about 5 deg. F. in mixing soft compounds. However, stiffer compounds requiring more power increased the temperature difference to as much as 30 deg. F. between the sensing thermocouple and the roll surface.

In the roll eventually developed by the Bureau, the water or steam flows from one end of the roll to the other through a central cavity and returns through 12 parallel ducts $\frac{3}{8}$ in. in diameter. The center lines of the ducts are $\frac{5}{8}$ in. from the roll surface. A well is provided so that a thermocouple can be placed within $\frac{1}{4}$ in. of the roll surface. The thermocouple lead wires are connected to slip rings at the end of the roll shaft.

Measurements of temperature changes in the surface of the roll following an abrupt change in coolant temperature show that the rate of heat transfer for the NBS roll is greater than for any of the rolls studied. A mill using these rolls and an automatic temperature control system has been in use at the Bureau for about a year. The automatic controller operates from a thermocouple in one roll and regulates the flow of water in a closed circulating system by means of three pneumatic diaphragm valves. Two of the valves admit water or steam to respective heat exchanges, and the third proportions the amount of water admitted to the rolls from each exchanger. This system controls the temperature of the roll containing the thermocouple within 2 deg. F. of the desired temperature during the mixing process. The temperature of the other roll may vary by as much as 7 deg. F. from the control point when there is a rapid change in the amount of power required. However, this variation could be reduced to about 2 deg., if necessary, by the use of a separate control system for each roll.

THE FRANKLIN INSTITUTE

MINUTES OF THE STATED MEETING

April 18, 1956

The Stated Monthly Meeting of The Franklin Institute was held on April 18, 1956, in the Lecture Hall. S. Wyman Rolph, President, called the meeting to order at 8:15 P.M. Approximately 350 members and guests were in attendance.

The President stated that the minutes of the March Stated Meeting were printed in the April JOURNAL. There being no corrections, changes or additions, they were approved as submitted.

The President then introduced the speaker of the evening, Dr. Fred L. Whipple, Professor and Chairman of the Department of Astronomy at Harvard and Director of the Astrophysical Observatory of The Smithsonian Institution. His talk on "The Scientific Value of Artificial Satellites" was well received by the audience.

The meeting adjourned at 9:35 P.M., with a rising vote of thanks to Dr. Whipple.

CECIL M. WATERBURY
Assistant Secretary

COMMITTEE ON SCIENCE AND THE ARTS

(Abstract of Proceedings of Stated Meeting held Wednesday, April 11, 1956.)

HALL OF THE COMMITTEE,
PHILADELPHIA, APRIL 11, 1956.

MR. FRANCIS B. FOLEY in the Chair.

The following reports were presented for final action:

No. 3300: Brown Medal.

This report recommended the award of the Frank P. Brown Medal to Robert G. LeTourneau, of Longview, Texas, "For his revolutionary improvements in earth moving equipment, with vast benefit to public works and private building construction."

No. 3301: Levy Medal.

This report recommended the award of the Louis E. Levy Medal, jointly, to Arthur W. Burks, Carl H. Pollmar, Don W. Warren, Jesse B. Wright, of Ann Arbor, Michigan, and Robert McNaughton, of Palo Alto, California, "In recognition of their outstanding paper, 'The Folded Tree,' appearing in the July and August, 1955 issues of the Journal of The Franklin Institute."

JOHN FRAZER,
Secretary to Committee.

MEMBERSHIP

ACTIVE MEMBERS ELECTED BY THE BOARD OF MANAGERS
April 18, 1956

ACTIVE FAMILY

William F. Blake
John Jensen
John R. Lentz
John Ennis Pepper
Earl S. Walter
Roy B. Williams

ACTIVE

Kipling Adams
Rolph Albert
N. Edward Berg
Bernard Blackman
William W. Bossler
Samuel H. Daroff
Robert G. Dunlop
Paul S. Earley
J. M. Farrin
Alfred A. Fini
Mrs. Nancy K. Ford
Sidney Goldstein
David Gwinn
Ralph E. Harris
Max Hirsch
Walter Hyett
John R. Kingston
Donald E. Moat
S. Rowland Morgan
Donald M. Mounce
Robert E. Oberholtzer
W. C. Pierson
Horace A. Reeves
Mary C. Smith
Harvey Springel

ACTIVE NON-RESIDENT

Earl S. Belote
Paul H. Groff
George W. Kessler
Arthur W. Lo
Francis A. Raymaley

NECROLOGY

Hugo Barol '47
William L. Brown '25
Edmund W. Dingle '45
Hugh S. Gilhams '36
Richard E. Hanson '42
Malcolm W. Stottler '51
C. C. Tutwiler '99
Joseph C. Yaskin '46

LIBRARY

The Committee on Library desires to add to the collections any technical works that members may wish to contribute. Contributions will be gratefully acknowledged and placed in the Library. Duplicates received will be transferred to other libraries as gifts of the donor. 680 items have been added the past month.

Photostat service. Photostat prints of any material in the collections can be supplied on request.

The Library and reading room are open from 9 A.M. until 5 P.M. on Mondays, Tuesdays, Thursdays, Fridays, and Saturdays; and 2 P.M. until 10 P.M. on Wednesdays. Beginning June 1, Saturday hours will be from 9 A.M. until Noon.

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NOTES FROM THE FRANKLIN INSTITUTE MUSEUM

A. C. CARLTON, DIRECTOR

COMPUTATION EXHIBIT

Visitors who have become accustomed to the collection of machines in the Prime Movers Section will miss the familiar wheels going around. This area has been cleared in order to provide space for the installation of the UNIVAC, a large electronic computer. This does not mean that we shall be deprived of all our exhibits illustrating the early stages of power development. A group of exhibits has been retained which will present a thumb-nail sketch of the progress from animal power through water wheels, the recriprocating steam engine, to steam turbines. These will be displayed in a corridor leading from the Lounge.

Other exhibits have been placed in storage pending the time when more display space can be made available for a better integrated story of the prime movers.

"Today is not yesterday," wrote Carlyle, "We ourselves change. How then can our works and thoughts, if they are always to be the fittest, continue always the same? Change, indeed, is painful, yet ever needful; and if memory have its force and worth, so also has hope." In parting with some old associations we have the consolation of knowing they will be replaced by an installation representative of the future.

Some of our visitors will recall the astonishment which greeted the operation of the first UNIVAC when it was shown in the Engineering Progress exhibition in April, 1947. The device has grown since the initial one was built, and it is fair to say visitors will be entranced by witnessing the performance of this new electronic computer capable of solving problems at breathless speed that would have involved the employment of minds and hands of many mathematicians over the period of several months. The device is still too young for its manifold potentialities to be explored, but without any doubt it has a vast future.

Although the computer will have a place in the operations of the Institute Laboratories' activities, it will, nevertheless, be so arranged that Museum visitors will be able to witness it at work and have its operation explained. But, first, there will be an exhibit area in which the whole history and mechanics of the science of computation will be illustrated. Our word "calculate" is derived from the Latin *calculi*, the pebbles used in counting, so our exhibits will begin with the pebbles used in ancient days to perform simple computations. The abacus, familiar to most of us from kindergarten days, is still used as a computing device in the Orient. In the hands of an expert it produces results that con-

found an occidental laboriously figuring with pencil and paper. It is probably the first of all calculating machines.

After Blaise Pascal invented the first mechanical calculating machine, a number of ingenious men improved upon it, so that today we have excellent cash registers in use to show the efforts at improvement were not unavailing. But the developments did not all involve whirring wheels. Mathematicians evolved other devices, such as Napier's "bones" and the slide rule. These and other fundamental steps in computation, will be shown dynamically and graphically in this series of exhibits designed to serve as an introduction to the new electronic computer.

Another section of the exhibits will show how the UNIVAC works in detail, and a small theatre, where talks will be given on the subject of computation and computers, will permit the viewing of motion pictures.

Finally, a viewing platform will enable visitors to gather an impression of the high speed with which the electronic device acts, the enormous amounts of information it can assimilate, and the accuracy of its results. As the intricacies of the giant computer may seem incomprehensible to the lay mind, the greatest care is being taken to ensure that everyone will carry away an understanding of its operation and accomplishments. An especially instructed guide will be available.

Since the electronic computer will fill an important function in the solution of deeply involved scientific and engineering problems it will be a valuable instrument in the expansion of knowledge. But it will also come nearer to the ordinary person in complicated business problems involving numerous calculations, such as the compilation of pay rolls in large concerns.

It is hoped to have the exhibit completed in the fall.

NOTES FROM THE FRANKLIN INSTITUTE LABORATORIES FOR RESEARCH AND DEVELOPMENT

NICOL H. SMITH, DIRECTOR

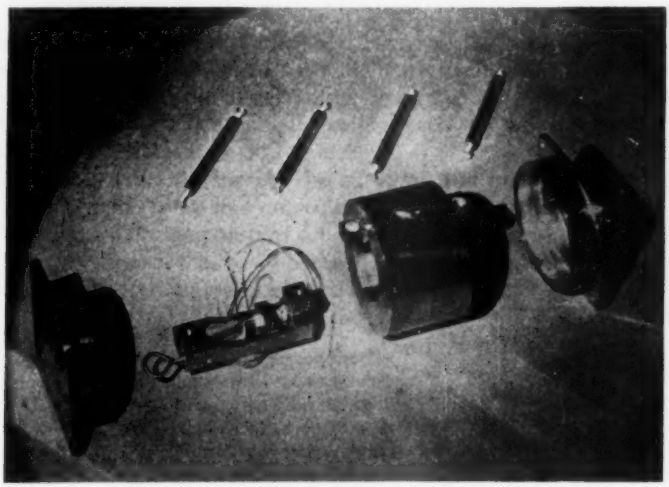
DYNAMIC THRUST METER

BY

AXEL O. BERGHOLM

In modern high-speed military aircraft it is no longer possible for the aircraft crew to bail out merely by jumping from the craft. It is now the practice to eject a man and his seat as a unit. This is done by a special cartridge that is attached to the seat. The operation of the cartridge must be dependable and produce an ejection force that is not deleterious to the personnel. The reliability is determined by laboratory tests in which the thrust of the cartridges is recorded.

Under a contract with Frankford Arsenal our Engineering Mechanics Section developed a proving-ring-type dynamic thrust meter to determine the thrust developed by the cartridges. The sponsor required that the thrust meter have a maximum height of 3.25 in. in order that it fit the test facility, that its natural frequency be high enough to record the force *vs* time curve developed by the mortar, and that it be able to record a maximum force of 10,000 lb.



Exploded view of thrust meter showing the end covers detached, and the beam and transducer assembly removed from the ring.

The product of the development was a proving ring of unusual proportions. The outside diameter was 3 in., the inside diameter was 1.5 in., and the width 2 in. Due to this small size it was not possible to attach the strain measuring device inside the ring. A beam was passed through the ring, to which the device was attached; the beam was attached to the faces of the ring. The device to measure the ring deflection was an RCA No. 5734 Mechano Electronic Transducer. The beam and transducer assembly was attached to the top of the ring while a shaft was attached to the bottom of the ring. The top end of the shaft deflects the plates of the transducer, the output of the transducer being fed into an oscilloscope.

From tests of the thrust meter it was determined that two natural frequencies existed. One was 4000 cps. and the other 12,000 cps. These values are well above the frequencies experienced in the testing of the cartridges. The static deflection of the meter was 0.0012 in. under a load of 10,000 lb. With the use of delicate electronic equipment it was possible to detect the application of several pounds load to the ring. This demonstrates the sensitivity of the ring and transducer assembly.

Since this is a dynamic meter, "drift" is of no importance. Nevertheless, because the long-time drift of the transducer was found to be less than 100 lb., the meter could also be used for static measurements at high loads.

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION

ELLICE McDONALD, M.D., FOUNDER WILLIAM G. BATT, D.Sc., DIRECTOR

EFFECT OF ACRIFLAVINE ON THE GROWTH OF THE KREBS 2 ASCITES TUMOR OF MICE

BY

J. O. ELY AND W. G BATT

Certain of the acridine dyes were found by Lewis *et al* (1) to inhibit tumor growth in mice when incorporated in the diet. Tumor growth, however, may be influenced not only directly by selective action on the tumor but indirectly by its influence on the host animal. Since these dyes are toxic it was considered of interest to compare the effect of one of the dyes, acriflavine, not only on the tumor but also on the host.

In order for a chemical compound to cause the death of tumor cells it is necessary that a certain minimal concentration of the chemical be maintained in the cells for a sufficient time. A high concentration for a short period of time or a lower concentration for a longer period of time may be equally effective.

Acriflavine, when injected into the peritoneal cavity of Krebs 2 ascites tumor-bearing mice promptly entered all tumor cells and could be detected by its fluorescence. Hematoporphyrin, on the contrary, did not enter the living cells, but was promptly absorbed by dead ones. These cells fluoresced brilliantly red.

Thus with Krebs ascites tumor-bearing animals treated with acriflavine it was possible to determine if the dye had entered the ascites cells and whether or not any of the cells present at the time of observation were dead cells.

The effect of acriflavine on the survival and growth of immature non-tumor-bearing mice was determined as a measure of toxicity. All mice were fed a diet composed of 7 parts casein, 4 parts salt mixture, 68 parts sucrose, 2 parts Vitab, 10 parts mazola, and 9 parts of inert filler. Eight groups of 15 mice were treated as follows:

1	Control group	
2	Fed 0.05% acriflavine in the diet	
3	Dye administered subcutaneously	0.25 mg. daily
4	Dye administered subcutaneously	0.125 mg. daily
5	Dye administered subcutaneously	0.05 mg. daily
6	Dye administered intraperitoneally	0.1 mg. daily
7	Dye administered intraperitoneally	0.05 mg. daily
8	Dye administered intraperitoneally	0.025 mg. daily

The Krebs 2 ascites carcinoma in Swiss mice was used in the studies of the effect on tumor growth. Administration of the dye intraperitoneally, subcutaneously or in the food was begun 24 hr. after implantation of the tumor (5×10^6 cells).

In order to determine whether the dye had entered the tumor cells and whether any cells were dead, a small amount of ascitic fluid was withdrawn from the peritoneal cavity into a one ml. syringe containing about 0.1 ml. of hematoporphyrin in solution such that the concentration of hematoporphyrin was approximately one part in 500,000.

Observation of quartz slide preparations viewed through a micro-

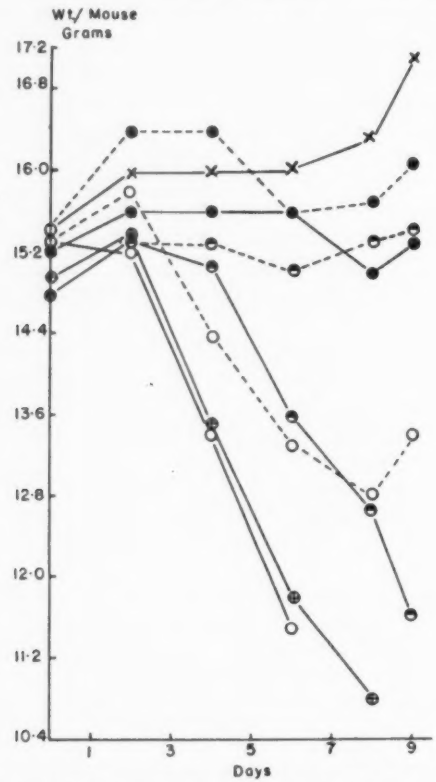


FIG. 1. The effect of acriflavine on the growth of immature mice.

Control group			No deaths
Fed 0.05% acriflavine in diet			7 deaths
Dye Subcutaneously		0.25 mg. daily	15 deaths
Dye Subcutaneously		0.125 mg. daily	4 deaths
Dye Subcutaneously		0.05 mg. daily	1 death
Dye Intraperitoneally		0.1 mg. daily	3 deaths
Dye Intraperitoneally		0.05 mg. daily	no deaths
Dye Intraperitoneally		0.025 mg. daily	no deaths

scope equipped with a quartz condenser and illuminated with light[1] of predominant wave length of 3650 Å enabled the detection of acriflavine in the cells at a dilution of one part acriflavine in 1×10^6 parts of cell suspension. At the same time any dead cells fluoresced brilliantly red because of hematoporphyrin within them.

The effect on growth and survival during 8 days is represented by Fig. 1. It was decided to use 0.025 mg. of acriflavine daily intraperitoneally, 0.05 mg. daily subcutaneously and 0.01% in the diet as safe doses in the tumor experiments.

The effect of the dye on tumor growth is shown in Table I. The most effective treatment was by intraperitoneal injection; 0.25 mg.

TABLE I.—*Effect of Acriflavine on Krebs 2 Ascites Tumor Growth.*

Method of treatment	Daily dose	Days in experiment	Number of mice	Tumor cells per mouse (millions)	Inhibition of tumor growth (per cent)
None	0	5	13	224	—
Subcutaneous injection	0.25 mg.	5	13	145	35
Intraperitoneal injection	0.25 mg.	5	10	0	100
None	0	5	12	403	—
Diet	0.01%	5	12	297	26
Subcutaneous injection	0.05 mg.	5	12	324	20
Intraperitoneal injection	0.025 mg.	5	12	57	86

daily for 5 days completely eliminated the tumor. All the tumor cells in a sample of ascitic fluid removed two minutes after intraperitoneal injection of 0.25 mg. of the dye fluoresced brilliantly. There was still considerable fluorescence of the cells 24 hr. later. Thus this dose given daily intraperitoneally maintained a comparatively high concentration of the dye in the tumor cells with good results so far as tumor inhibition was concerned. A dose of 0.025 mg. of the dye given intraperitoneally caused prompt fluorescence of the tumor cells, but the dye was almost completely absent from the tumor cells 24 hr. later. This dose given daily inhibited tumor growth by 86% and inhibited the growth of immature mice by about 50% but caused no deaths. The effect appeared to be greater on the tumor than on the host. The fluorescence of alcoholic extracts of liver, spleen and pancreas showed that both doses (0.25 and 0.025 mg. daily) caused accumulation of the dye in these organs. A dose of 0.25 mg. daily, which eradicated the tumor was obviously too great since even 0.1 mg. daily caused much loss in weight and some deaths of immature mice.

The daily subcutaneous administration of 0.25 mg. of the dye inhibited tumor growth 35% and in the toxicity experiments caused

[1] The light generated by a General Electric A-H 6 mercury lamp was monochromated and the 3650 Å band passed through a No. 5840 Wratten filter for use. A K_2 Eastman Kodak Company filter was utilized as a secondary filter.

much loss in weight and the death of all the experimental animals. A dose of 0.05 mg. daily, which had only a mild effect in the toxicity tests, inhibited tumor growth by 20%.

Twenty-four hours after the first subcutaneous administration of 0.25 mg. of the dye only a faint fluorescence of the tumor cells was observed, but 24 hr. after the second dose there was considerable fluorescence of the tumor cells. Thus considerable time elapsed before subcutaneously injected dye appeared in the tumor cells and the concentration in the cells was small compared to that following intraperitoneal injection. It appears probable that the host was injured more than the tumor since the dye was found to be present in spleen, pancreas, kidneys and liver and that most of the tumor inhibition was caused indirectly by an effect on the host.

Examination of tumor cells from mice given subcutaneously 0.05 mg. of the dye daily for 4 successive days failed to show the presence of the dye in the tumor cells 24 hr. after each dose. However, doses of 0.05 mg. daily inhibited tumor growth by 20%. This dose also completely inhibited growth of immature mice and caused some loss in weight. Tumor growth inhibition at this dosage appears to be a reflection of an adverse effect on the host.

Fed in the diet at a concentration of 0.05%, acriflavine caused much loss in weight and the death of about 50% of the mice. At a concentration of 0.01% in the food, tumor growth was inhibited by about 25%, but 23% of the mice died. Tumor cells fluoresced with acriflavine very faintly. The detrimental effect on the host mice appeared to be greater than the effect on the tumor.

During the examination of the tumor cells in the presence of hematoporphyrin only a very small percentage of the cells had absorbed hematoporphyrin. This indicated that some cells were dead at the time of examination. The method would give no indication of the possible death and disintegration of cells during the time between examinations.

These experiments indicate that acriflavine will effectively inhibit the growth of the Krebs ascites tumor of mice if it is maintained in contact with the tumor cells in a sufficient concentration. However, the toxicity appears to be no greater for the tumor cells than for the cells of the host, so to be used successfully it would be necessary to devise a method to deliver the dye to the tumor in a greater concentration than to the rest of the animal. Intraperitoneal injection was found to be the most effective method of administration to mice bearing the Krebs 2 ascites tumor.

REFERENCE

(1) M. R. LEWIS, P. P. GOLAND AND H. A. SLOVITER, *Anat. Record*, **96**, 201 (1946).

JOURNAL OF THE FRANKLIN INSTITUTE

The following papers will appear in this JOURNAL within the next few months:

HERRMANN, JACOB AND C. S. ADES: Experimental Verification of Circular Plate Bending Theory

HEYDA, JAMES F.: An Elementary Derivation of the Formula for the Windage Jump of a Spinning Shell

CUNNINGHAM, W. J.: Graphical Solution of Certain Nonlinear Differential-Difference Equations

COULSON, THOMAS: Philadelphia and the Development of the Motion Picture

MITCHELL, E. H.: Analysis of Magnetic Circuits with Given D-C. Excitation

BATTEN, H. W., H. L. SMITH AND H. C. EARLY: Plasma Fluctuations in Crossed Electric and Magnetic Fields

PIPES, LOUIS A.: Matrix Theory of Skin Effect in Laminations

PENFIELD, ROBERT AND HENRY ZATZKIS: The Relativistic Linear Harmonic Oscillator

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PUBLICATIONS RECEIVED

THE MEANING OF RELATIVITY, by Albert Einstein. Fifth edition, including the relativistic theory of the non-symmetric field, 169 pages, 5¼ × 7¾ in. Princeton, Princeton University Press, 1956. Price, $3.75.

ELECTRONS, WAVES AND MESSAGES, by John R. Pierce. 318 pages, diagrams, 5¼ × 8 in. New York, Hanover House, 1956. Price, $5.00.

EPREUVES SUR ECHANTILLON, by Maurice Dumas. 170 pages, 6¼ × 9¼ in. Paris, Centre National de la Recherche Scientifique, 1955. Price, 1000 fr.

ART IN COINAGE, by C. H. V. Sutherland. 223 pages, plates, 5¾ × 8¾ in. New York, Philosophical Library, 1956. Price, $7.50.

TO MEMBERS AND THOSE WHO KNOW THE FRANKLIN INSTITUTE

All of us associated with The Franklin Institute are gratified by the support given by its benefactors in the past. Without their generosity our privately endowed Institute would have been unable to serve industry, the professions, and the public as it has and should.

There is still a continuing and pressing need of contributions and bequests —both for general and specific endowment, and of income to be judiciously used. Your response will be most earnestly appreciated.

Checks should be made payable to The Franklin Institute, and sent to The Franklin Institute, Benjamin Franklin Parkway at 20th Street, Philadelphia 3, Pennsylvania.

Where property is transferred, title should be in the name of The Franklin Institute of the State of Pennsylvania for the Promotion of the Mechanic Arts.

We shall be glad to supply any additional information regarding gifts and memorials. Please write to the above address, attention of the Endowment Department.

BOOK REVIEWS

TITANIUM. METALLURGY OF THE RARER METALS No. 4, by A. D. McQuillan and M. K. McQuillan, edited by H. M. Finniston. 466 pages, diagrams and illustrations, 5½ × 8½ in. New York, Academic Press; London, Butterworths Publications; 1956. Price, $10.00.

The current series, "Metallurgy of the Rarer Metals," edited by H. M. Finniston, now include the four books, Chromium, Zirconium, Manganese, and Titanium. These books are thorough, up-to-date compilations of existing information concerning the rarer metals. The newest text, Titanium, is a timely addition to the group. Probably more research effort has been devoted to titanium in the last several years than to any other metal. As a result, the literature is flooded with a vast amount of valuable information. To compile this information into one source is a formidable task that is made even more difficult by the fast rate at which new data are being published. The authors do an extremely creditable job and have maintained the high standards set by the previous authors of this series.

The text opens with a conventional discussion of history, occurrence, and recovery of titanium from its ores. The authors then discuss in detail the industrial production of titanium and its purification. The relative newness of these methods is apparent when we realize that in 1948 only 3 tons of titanium were produced in the United States as compared to 7000 tons in 1954.

A particularly good chapter is devoted to the melting and casting of the metal. Due to its high melting point (1670°C.) and reactivity, titanium is a difficult metal to melt and cast. The authors describe in detail the various aspects of the problem from a laboratory to an industrial scale. Many schematic diagrams are shown to illustrate the various methods whereby one can successfully melt and cast titanium.

One quarter of the book is devoted to the constitution of titanium alloys. Over 40 binary systems are covered. The authors open this section with a very excellent discussion concerning the problems involved in constitutional studies of titanium alloys. They are very well qualified to do so since they have contributed considerably to the published literature concerning phase diagrams.

Among the many other subjects covered are deformation mechanisms, transformations, mechanical and physical properties, heat-treatment, corrosion, reaction with gases, metallography, fabrication, and joining.

One of the outstanding features of this book is that the authors do not just present data as collected and summarized from the literature. They discuss the general principles involved so that even though the data become outdated, the text will still be of considerable use to those interested in titanium and its alloys.

This book is very well illustrated, completely referenced and contains a subject index. The technologist and research worker will find it an extremely useful textbook.

R. L. SMITH

BOLTZMANN'S DISTRIBUTION LAW, by E. A. Guggenheim. 61 pages, 12 × 19 cm. Amsterdam, North Holland Publishing Co.; New York, Interscience Publishers Inc.; 1955. Price, $1.50.

This book, or booklet as the author calls it, is a neat little package as regards both size and content. It slips into your pocket as easily as a twenty-five cent novel. And for those with a background of advanced calculus and elementary physics, chemistry and physical chemistry, it is as readable and exciting as a novel. The author begins by introducing the elements of quantum mechanics and showing that classical mechanics is an approximation applicable to planets, projectiles and grains of dust, sometimes inadequate for molecules and atoms and completely misleading for electrons.

He then states the important properties of temperature and shows that there is one particular kind of temperature scale in terms of which the distribution law over quantum states takes an especially simple form. The temperature on such a scale is called the absolute temperature and the distribution law is Boltzmann's. This law describes by far the most important property of absolute temperature and is used as the starting point for all problems involving temperature. The author then defines the "sum of states" or partition function and then using the distribution law and the partition function proceeds to derive the dependence on temperature of the equilibrium properties of matter in bulk

without any formal statement of the laws of thermodynamics or any mention of entropy.

The student will find a detailed development of the properties of ideal monatomic and diatomic gases, the derivation of the formula for the pressure of a perfect monatomic gas by the use of the properties of partition functions, and a discussion of the superfluous principle of equipartition of energy. The discussion also covers simple crystals, phase equilibrium in which the Clapeyron formula is derived, dielectric constant of a gas, chemical equilibrium in the gas phase and finally the exact distribution laws, known as the Fermi-Dirac and Bose-Einstein distributions. The Boltzmann distribution is stated to be an approximation which is valid for almost all systems, the most important exception being the system of conducting electrons in a metal.

The author uses many examples and states the physical meaning of the derived relations. The agreement with experiment is also indicated. The language is precise and clear. The author mentions several times statements, commonly occurring in textbooks, that are pure nonsense. While the author states he hoped the book might be written by someone with more experience in elementary teaching, this reader feels that he should not apologize but should be prevailed upon to write some elementary textbooks himself. This booklet is highly recommended for students of physics and chemistry who have the background mentioned above.

W. E. SCOTT

ELECTRONIC ENGINEERING, by Samuel Seely. 525 pp., 6 × 9 in., drawings and diagrams. New York, McGraw-Hill Book Co., Inc., 1956. Price, $8.00.

In several of his books Samuel Seeley refers to the MIT Radiation Laboratory as a major source of the material. The reviewer also chanced to have been a staff member of this laboratory at the time the author was engaged there and feels that Professor Seely is certainly as qualified as any to describe the pulse circuitry of wartime radar. His earlier books, "Radio Electronics" and "Electron-tube Circuits," define his field of work both as an engineer and more recently as a professor. The latest book now extends his teaching, as all books for the electronics engineering profession must, into the realm of solid-state theory and the transistor.

This is not an advanced book dealing with a specialty, but could be used as the basis for a rather comprehensive course covering a dozen or more of the currently important electronics subdivisions. The characteristics of many kinds of electron tubes are discussed both from the viewpoint of their internal mechanics of operation and as circuit elements. The author also takes up their use in amplifying and computing circuits, following these subjects with an analysis of oscillators, heavily biased relaxation circuits, and special sweep generators. The book is brought up to date with a chapter on the solid-state physics of transistors, and the last chapter introduces transistors as circuit elements by giving a number of equivalent circuits which may be used in designing practical devices. Problems are supplied for all chapters, and a list of recent references adds to the resourcefulness of the presentation.

Professor Seely's long association with radar is evident in the variety of circuits which he uses in the test examples and problem sections. These include the many trigger and pulse circuits found in radar indicators and modulators. Of course these techniques are appropriate today in the television and computing machine applications which will become the absorbing interest of many of the present students.

The text appears to contain an appropriate combination of basic circuits, discussion of the theory of operation, and an analytical treatment of each typical device. In the first few chapters the author attempts to skim a basic part of electronics, particularly amplifier principles, in a very brief manner. These first three chapters have been the subject of lengthy textbooks in the past, and it is only fair to caution the student and teacher that there is still as much to these subjects as ever there was. The reviewer will therefore issue once again the complaint that the superficial treatment of these chapters tends to unbalance the book and detract from its competent treatment of the newer circuits in later chapters. It would have been better to refer the student to the many thorough books on conventional vacuum tube and amplifier principles, going directly to feedback, computing and pulse circuits in the first chapter. However Professor Seely has much company in numerous contemporary authors who feel they dare not write on any phase of electronics

without first a faint rehash of tubes and amplifiers in their beginning chapters.

C. W. HARGENS

SURVEYING FOR CIVIL ENGINEERS, by Philip Kissam. 716 pages, illustrations, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1956. Price, $8.50.

This book deals with the ancient subject of surveying brought up-to-date. It should prove of value to the engineering student who has completed a course in the fundamentals of surveying and to the experienced Civil Engineer who wishes to become familiar with the modern instruments and methods.

The text is composed of five parts. The first part covers instruments and methods for large surveys. The second part covers the operation of different types of surveys and the third deals with procedures for precise controls. Aerial mapping is in Part IV and Part V is the Appendix.

In Part I is an excellent discussion on accuracy and errors which should be thoroughly understood before proceeding with a problem and the planning of a surveying problem. Other chapters deal with leveling, horizontal and angular measurements, compass surveying, adjustment of level nets and traverses, stadia surveys and planning a survey. All of this is a practical presentation in which examples are given and, therefore, should be valuable to the young engineer.

In Part II the methods are applied to actual surveying operations as celestial observations, boundary, land, city, mine hydrographic, bridge, tunnel surveying and steam gaging. Again actual problems are done and well known applications are cited in detail as in the case of the recently completed Tampa Bay Bridge in Florida. These are things that should make this book valuable to the beginner and interesting reference to the practicing engineer.

Part III deals with precise level net, triangulation, and traverse nets. The procedures, errors and adjustments are fully covered.

Part IV is devoted to aerial mapping as applied to large engineering projects and not for those particularly interested in geodetic surveying.

In the Appendix is a more complete treatment of probability, least squares and the theory of state coordinate systems that is not found in the text.

It is recommended that this book be in the library of the young civil engineer as a ready reference and to the experienced engineer as a refresher course in modern surveying.

A. O. BERGHOLM

CONTROL OF NUCLEAR REACTORS AND POWER PLANTS, by M. A. Schultz. 313 pages, diagrams, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1955. Price, $7.50.

A prominent and unique place in the field of nuclear engineering will be occupied by *Control of Nuclear Reactors and Power Plants*. This book presents the most complete coverage to date of the many problems that are peculiar to the control of a nuclear reactor which is an integral part of a steam-producing power plant. Drawing from the writings of the many engineers and scientists who have worked at the Westinghouse Atomic Power Division under his direction, as well as many outside sources, and works of his own, the author treats many of the practical aspects of control instrumentation, control components, and control systems, as related to nuclear power plants.

The author states in the preface that the descriptive and illustrative material in the book relates to one specific type of reactor, the solid-fuel heterogeneous reactor. In fact, a great amount of this material is directed towards one particular reactor in that category—the pressurized, water-cooled-and-moderated, "thermal" reactor. The reader should always keep this fact in mind, to avoid confusion when considering the control of other types of reactors. However, making allowances for the differences in the control characteristics of the various reactor types, the reader will find that many of the principles and techniques of control system design which are covered in the book are generally applicable in the power reactor field.

Chapters 1 through 3 introduce, respectively, the characteristics of the nuclear power plant as a whole, the elementary physics of reactor control, and the mathematical relationships governing the kinetic behavior of the nuclear reactor. Like the rest of the book, most of the material in these chapters relates to one specific type of thermal reactor.

The application of the conventional methods of servomechanism analysis and synthesis to reactor control systems is the principle subject of Chapter 4, which is entitled "Automatic Reactor Control." A brief description of reactor control systems and their characteristics is included in this chapter.

Chapter 5 is devoted to a discussion and description of the various types of mechnisms which may be employed to move neutron-absorbing control rods in and out of a reactor. Control rods are presently the most widely used method of controlling the fission process in a nuclear reactor—the use of control rods is assumed throughout the book.

Chapter 6 considers the control problems which arise when a nuclear reactor is connected to a steam-producing plant. Here, the specific example of a pressurized, water-cooled-and-moderated, thermal reactor power plant is analyzed. In terms of block diagrams, frequency response plots, and transient response curves, it is shown how the dynamic characteristics of the reactor, its coolant loop, and the steam plant all combine to give the over-all characteristics of the nuclear power plant. Several power plant control systems are described and their characteristics discussed.

Reactor control radiation detectors, their use and methods of calibration are discussed in Chapter 7.

A very interesting and informative discussion of reactor operational control problems is presented in Chapters 8 through 10. Reactor startup, power operation, and shutdown are each considered in detail.

The 11th and final chapter of the book presents a brief summary of the electronic simulator techniques which have been developed for the analysis and synthesis of nuclear power plant control systems.

The author has done an excellent job of organizing and presenting his material. The many numerical computations, presented in both tablular and graphical form, should be extremely valuable to the newcomer in the reactor control field, who would like to obtain a "feel" for the orders of magnitude involved in nuclear power plant control.

The reviewer recommends this book as essential reading to anyone who is involved, or plans to become involved, in the field of reactor control.

G. S. STUBBS

ENGINEERING DRAWING AND GEOMETRY, by Randolph P. Hoelscher and Clifford H. Springer. 517 pages, illustrations, photographs, charts, tables $8\frac{1}{2} \times 11$ in. New York, John Wiley & Sons, Inc.; London, Chapman & Hall, Ltd.; 1955. Price, $8.00.

The multiple objectives of the authors have been exceeded in compiling a work that, besides being an outstanding text book for the engineering student, should become an authoritative reference book for many modern engineering offices in the United States, Canada and Great Britain.

Chapters one, two and three of the 29-chapter-book deal with fundamentals such as lettering and instrument handling, and the 60-table ultra modern appendix includes its own table of contents. Aside from the foregoing, this book pays little attention to the development of manual proficiency, and concentrates on thorough understanding and proper application of underlying principles of engineering and its graphic presentation.

Problems are included which, together with available work books for both drawing and geometry, provide sound thought-provoking training material for the student.

Experience is demonstrated even in the detail of page size—large to avoid undue eye strain—in each of the hundreds of line drawings, charts, maps and graphs, as well as printed descriptive material. Also, the pages lie flat enough to avoid the necessity of using additional weights.

The combined backgrounds of the authors have fitted them for the task of preparing this book, from both a theoretical and a practical viewpoint. Credit is given to many experienced associates in educational and industrial fields, together with numerous companies which have contributed to its content.

Many of the accepted standards adopted by the three governments—USA, Great Britain and Canada—and industry at large, are the direct outcome of work done by these men while directing and serving on the committees delegated to pool their engineering knowledge in establishing these standards.

E. R. BOWMAN

LES APPLICATIONS DU RADAR A L'ASTRONOMIE ET A LA METEOROLOGIE, by J. Van Bladel. 147 pages, diagrams, 6¼ × 9¼ in. Paris, Gauthier-Villars, 1955. Price, 1600 fr. ($4.70 plus 45 fr. postage).

The great advancement in radar due to the war effort is reflected in the applications of this new field for the benefit of everyone. The book *Les Applications du Radar a l'Astronomie et a la Meteorologie*, by Dr. J. Van Bladel, is a compact exposition of these developments.

A seventeen-page introductory chapter explains radar technique with sufficient detail to clarify the succeeding chapters.

The second chapter covers detection of celestial bodies. This brings back memories of the Army's efforts to bounce signals off the Moon during the war. Even the zodiacal light is touched in covering the whole celestial sphere.

The chapter on meteors covers the great new field of which daylight observation is unique. The ionized trails left by meteors can be worked and followed with the sun shining. This enlarges by 50 per cent the field of upper atmosphere studies. Radiants that have been unknown are accurately plotted with ease. Aurora ionization also bounces signals that help to clarify this popular mystery.

Detection of precipitation in the form of rain, snow, and hail benefit the weather bureau. Hurricane tracking will reduce the destructive effect of these storms. Storm warnings and prediction of expected paths can pinpoint effective measures to evade destruction from these tropical menaces.

The 196 entries in the bibliography show the diversity of papers and the mass of work being done, with world wide coverage, in this field. Radar adds a long arm to scientific investigation. EDWIN F. BAILEY

PRINCIPLES OF METAL CASTINGS, by R. Heine and P. Rosenthal. 639 pages, diagrams and illustrations, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1955. Price, $7.50.

Prepared primarily as a textbook for undergraduates in metallurgical engineering and for use in service courses for the associated engineering curricula, this book is very complete in detail of foundry principles and actual methods. It is so arranged that portions may be omitted for the less involved survey courses. The text material covers the various casting processes, molding materials and equipment, gating and feeding techniques, mold sand technology, casting design and melting procedures for the common casting metals. In addition, the metallurgical principles are presented in connection with melting solidification, alloying properties, heat treatment and fluid flow of metals. These principles are explained in terms of how they can be applied to the problems of the foundry; for example, feeding of casting in terms of fluid flow principles. It is felt that the principles of gases in metals could have been elaborated to a greater extent.

In general, the material is so presented that the student may read the "why" and "how" of the foundry. MARVIN HERMAN

ADVANCES IN CANCER RESEARCH, Vol. III, edited by Jesse P. Greenstein and Alexander Haddow. 369 pages, diagrams, 6 × 9 in. New York, Academic Press, Inc., 1955. Price, $8.50.

One of the outstanding features of this volume, as well as the previous ones, is the careful selection of contributors. Volume 1 contained 12 authors writing 10 essays; volume 2 contained 13 authors writing 10 essays; while the present volume has 7 authors contributing 6 papers. The six areas of investigation reviewed and interpreted include statistics, biology and chemistry, with some of the unavoidable overlapping of scientific disciplines which cancer research requires.

The first article deals with "The Etiology of Lung Cancer" by Doctor Richard Doll of London, England. He discusses statistical evidence which points to relationship of cigarette smoking, and various environmental factors, to the incidence of lung cancer. The circumstantial evidence indicates the need of further experimental and statistical verification.

Following is an article by Doctor Harold P. Morris of Bethesda, Maryland entitled "The Experimental Development and Metabolism of Thyroid Gland Tumors." The biochemical aspects are fully discussed. The value of radioactive iodine (I^{131}) as a tracer in metabolic studies of both normal and neoplastic thyroid cells is well illustrated by the in-

vestigations reviewed. The investigations also show that radioiodine (I^{131}) can exert both carcinogenic and chemotherapeutic effects.

The next essay, "Electronic Structure and Carcinogenic Activity and Aromatic Molecules" by Doctors A. Pullman and B. Pullman of Paris, France describes the newer developments of the electronic theory of the possible relationship between molecular structure and metabolic activity. The chemicals considered include unsubstituted polynuclear hydrocarbons as well as substituted deviatives of polycyclic hydrocarbons.

Then comes a contribution by Doctor P. Rondoni of Milan, Italy, entitled "Some Aspects of Carcinogenesis" in which the cause of cancer is discussed from the standpoint of change in entropy and the possible action of carcinogenic hydrocarbons in the living system.

"Pulmonary Tumors in Experimental Animals" by Doctor Michael B. Shimkin of Bethesda, Maryland, summarizes investigations concerning primary pulmonary neoplasms in animals, and selectively covers the literature from 1896 to 1953. In the section on pulmonary tumors in man, the author feels the data already available on the epidemiology of human cancer of the lung and from the laboratory seem sufficiently impressive to urge the initiation of public education and related public health measures toward the reduction in the individual consumption of tobacco, particularly in the form of cigarettes, and toward the control of atmospheric pollution that is becoming an ever-increasing problem in many urban centers.

The concluding contribution is "Oxidative Metabolism of Neoplastic Tissues" by Doctor Sidney Weinhouse of Philadelphia, Pennsylvania. This is an excellent critical review of oxidative and glycolytic metabolism of cancer tissues. He presents some of the data and conclusions of Warburg, Dickens, Potter and many other leaders in the field. Weinhouse takes issue with Warburg's explanation of the high glycolysis of tumor tissue as caused by damaged respiration. The contributor's comprehensive conclusion is ". . . It would be more accurate to state that the anaerobic glycolysis of tumor slices is so high that a normal respiration and a normal Pasteur Effect are incapable of eliminating it. This latter statement places the emphasis on the high glycolysis of tumor slices rather than on the respiration or on the absolute Pasteur Effect, neither of which are quantitatively diminished in neoplastic cells."

The book is well documented, lists ranging from 113 references to 301 references. This source of information should be of invaluable aid to those graduate students who are interested in the area generally termed "biochemistry," as well as the investigator who is eager to broaden his field of inquiry.

W. G. BATT
W. D. YUSHOK

THE SUN AND ITS INFLUENCE, by M. A. Ellison. 235 pages, diagrams, 5½ × 8¼ in. New York, The Macmillan Co., 1956. Price, $4.50.

One of the timeliest books to appear, particularly at this time, is one by the Principal Scientific Officer at the Royal Observatory in Edinburgh. Dr. M. A. Ellison has written a book which answers many of the questions which will be posed in the next few years as a result of the impending sunspot maximum set for the spring of 1957.

In February there was a startling increase in the background cosmic ray count by 100% and there were many accompanying radio "fadeouts" of varying duration. These were traced to the appearance of a hydrogen "flare" on the sun.

Why should the appearance of a hydrogen flare give rise to varied effects on the earth? What is the mechanism whereby entire cities and in some cases entire countries are cut off from communications with the rest of the world as though we had gone back a century in time? What types of radiations are emitted by the sun under these conditions and what effects do the various radiations have? These are all questions which are asked today and questions to which the answers are only now becoming apparent.

The author is eminently qualified to discuss the sun and its effects on the earth, for he has been involved in the investigation of solar phenomena and resulting terrestrial effects for many years. The answers given in this comprehensive and authoritative book will set the standard for many years to come.

The first three chapters, which deal with the sun and its radiation, the sun's activity

and the sun's atmosphere, contain material found in many places. However, when the author begins speaking about the ionosphere in Chapter IV, he begins detailing much information which can be found only in current periodicals. Chapters V and VI deal with solar flares and their terrestrial effects and the sun and the earth's magnetism. Here the author discloses his mastery of this subject.

The Sun and Its Influence is a thoroughly competent work separating speculation from verifiable fact. For those who study the sun, it is an invaluable aid. I. M. LEVITT

STRUCTURAL GEOLOGY FOR PETROLEUM GEOLOGISTS, by Wm. L. Russell. 427 pages, diagrams, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1955. Price, $7.50.

The purpose of this text, as stated by its author, is to present the information on geologic structure needed by petroleum geologists in the practice of their profession and especially information on those aspects of structure which bear on oil finding. The book is to be used as preparation for study of a previous publication by the same author *Principles of Petroleum Geology* (1951) each volume presenting subject matter which the other omits. A student completing a course based on these two books would have acquired a more detailed knowledge of structures favorable to petroleum production than he could have through study of texts on general geology. Such a course, it is true, would produce oil geologists, specialists, rather than geologists broadly competent in all field of geologic thinking. However, it is stated that about ¾ of all college students majoring in geology enter the mining and petroleum industries indicating a wide need of specialization along the lines here discussed. This new text used in a course preliminary to the author's "Principles of Petroleum Geology" ought, therefore, to find a useful application in universities.

This text, considered as a standard geology text, presents descriptions and explanations of the sometimes complex structures found in oil fields and supports the explanations with the necessary detailed illustrative data. This primary geological objective of the text is attained with precision and clarity and, therefore, from the point of view of geology the book can be considered a success. The text, however, differs somewhat in orientation from the standard geology text in that the attempt is made to adjust the students to the new trends in geologic thinking arising from the contributions made in the last twenty five years through the use of the techniques and disciplines of the physical sciences. The impact of these new methods has been felt in nearly all areas of geology but more in oil exploration than elsewhere. Professor Russell endeavors to equip his readers to understand the language of physics by placing emphasis on an accurate understanding of terms and definitions, physical as well as geological. His chapter on "Physical Principles and Model Studies" contains advice useful both to beginners in geology and to more experienced practitioners. In the past lack of knowledge of physical principles and of exact scientific terminology did not deter some eminent geologists from discoursing on phenomena involving physical facts and procedures with disastrous results. This is the situation which Professor Russell is endeavoring to correct through indoctrination at the student level. He says ". . . the lack of clear or consistent usage of . . . terms has rendered some of the publications of geologists difficult or impossible to understand. The meanings given to the (physical) terms are especially variable or confused."

The body of the text is made up of a series of seventeen chapters dealing with types of structures including folds, faults, joints and fractures, domes, buried hills, etc. etc. and with more general subjects such as maps, lithology, dating and classification of traps. We shall not endeavor to review all these chapters. Referring briefly to Chapter 5 "Faults"—this important subject is treated in unusual detail, the attempt being made to clarify some of the confusion introduced into the subject by earlier writers. Professor Russell says—"In many cases it would be necessary to know what theories a geologist held and possibly what college he attended in order to interpret his classifications (of faults)." This confusion arose from careless use of terms and from a lack of understanding of the physical forces and resistances involved.

Other basal subjects as Salt Domes, Continental Shelves and Structural Factors are given more than usual attention in their special chapters making up, all taken together, a well balanced, high quality coverage of the

most important features of earth structures of interest to petroleum geologists. Possibly the inclusion of a chapter on Tectonophysics might have afforded an opportunity to emphasize to students the relations of physical forces and properties to structural and tectonic features but the author no doubt felt that this area of knowledge lay outside the field selected for this volume.

In the way of mildly adverse criticism, it seems to the reviewer that the style of this work is somewhat wordy and repetitious. Judicious editing could probably have reduced the bulk of the volume somewhat without impairing its value as a text. Here and there careless constructions indicate hasty preparation of the material. The author's intimate acquaintance with Gulf Coast oil fields enables him to speak of these important areas with authority. However his statement on p. 212 that Gulf Coast domes show no well marked alignments would doubtless be questioned by some oil men. Although the system of alignment of these domes is not simple and, it will be admitted, not "well marked" nevertheless regularities can be detected and these appear to be in the nature of alignments. Since the domes originate from compressional forces in the salt basement it seems natural to expect linear arrangements more or less related to the orientation of the basin edge.

It is always possible to find fault with details in any publication. The reviewer thinks that, by and large, *Structural Geology for Petroleum Engineers* is excellent. Written from a modern view point it is fairly successful in correcting some of the deficiencies of earlier texts. Furthermore it should help to set the geologists of the next generation on firmer ground in dealing with the multitude of contacts developing between geology and the physical sciences.

C. B. BAZZONI

AN INTRODUCTION TO REACTOR PHYSICS, by D. J. Littler and J. F. Raffle. 196 pages, diagrams, 5½ × 8½ in. New York, McGraw-Hill Book Co., Inc., 1955. Price, $4.50.

An Introduction to Reactor Physics is based on a set of declassified lectures given by the authors to the Reactor School at the Atomic Energy Research Establishment in Harwell, England. The material is presented in scholarly, concise fashion by men who are internationally known in the field. This book is specifically aimed at the engineer and physicist who wish to know the necessary background for reactor design, and at students who are studying reactor physics as a part of their physics and engineering courses.

The early chapters present the fundamentals of elementary nuclear physics with emphasis on background material for an understanding of principles involved in the construction of a reactor. Later chapters cover, in detail, the calculations used in the critical size of a gas cooled, graphite moderated natural uranium reactor. This reactor is the type chosen by the British to start their nuclear energy power program.

The reader should note that this text concentrates on a thermal reactor of a special type, and that each type of thermal or fast reactor has its own peculiar problems.

This book is highly recommended both for its style and context, but particularly for students or engineers interested in the gas cooled, graphite moderated, natural uranium reactor.

F. L. JACKSON

MANUAL OF ELEMENTARY PRACTICAL CHEMISTRY, by R. D. Brown and T. A. O'Donnell. 185 pages, diagrams, 5½ × 8½ in. Australia, Melbourne University Press; New York, Cambridge University Press, 1955. Price, $4.75.

This rather brief volume of 185 pages succinctly presents the fundamentals of practical chemistry, and admittedly is pointed at the university student. The principles and procedures in such basic operations as gravimetric and volumetric analysis are given in clear detail and intelligently illustrated. The simplicity of approach to the many phases and concepts in chemistry should make intelligent reading to the student or to one who wishes to familiarize himself with the practical procedures in chemistry. For example, the principles and methods of calculation or investigation are presented in problems of acidimetry and alkalimetry, redox and precipitation titrations. Further in the book, discussion is held and details are given of semi-micro techniques in analysis and reactions of cations which are lucidly presented in tabular form.

As an elementary, practical text, the book is to be recommended.

SAMUEL MUCHNICK

BOOK NOTES

How Time Is Measured, by Peter Hood. 64 pages, illustrations, 6¾ × 9 in. New York, Oxford University Press, 1956. Price, $2.75.

Life in Fresh Water, by E. S. Brown. 64 pages, illustrations, 6¾ × 9 in. New York, Oxford University Press, 1956. Price, $2.75.

These two small volumes are the fifth and sixth of the Oxford Visual Series, dealing with scientific subjects. The series is designed to stimulate interest in the subject among those who know little or nothing about it. Although essentially picture books, the text is well written and ties in with the illustrations.

How Time Is Measured relates the story of time-keeping from ancient to modern times and covers the calendar, sun-dials, all kinds of clocks and their works, the chronometer, radio time signals, watches and daylight saving time.

Life in Fresh Water is an account of the plants and animals living in fresh water ponds, streams and marshes. In addition to outlining the living habits of the various forms of life—including feeding, breathing, reproducing—the book classifies the plants and animals and suggests methods for collecting specimens and maintaining them in aquaria.

Faster, Faster, by W. J. Eckert and R. Jones. 160 pages, illustrations, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1956. Price, $3.75.

Written by two staff members of Columbia University's Watson Scientific Computing Laboratory, *Faster, Faster* is a simple, yet accurate description of a giant electronic calculator. In nontechnical language, the IBM calculator NORC—a typical giant brain—is explained so that an understanding of these miracle calculators is possible for the layman. The book covers "memory," magnetic tapes, printing, instructions, punch card techniques, maintenance, operation, and, finally, gives a summary of the kinds of problems solved. Simple diagrams supplement the text. If you are fascinated by the electronic computers and have been awed by their complexity, this book should hold your interest, in addition to increasing your understanding of one of science's greatest achievements.

Fundamentals of Electroacoustics, by F. A. Fischer, translated by Stanley Ehrlich and Fritz Pordes. 186 pages, diagrams, 5½ × 8½ in. New York, Interscience Publishers, Inc., 1955. Price, $6.00.

This translation of a 1950 German work will be welcomed by those interested in the theory of electroacoustics. No special knowledge of acoustics is needed to study the present work, which is self-contained in that no outside references need be consulted, although a bibliography is included. (The translators have replaced the original bibliography with one containing references more accessible to English and American readers.) An introductory chapter on electric and mechanic oscillators is followed by chapters on the fundamental physical laws of electroacoustics and energy conversion, on the theory of electroacoustic transducers, on the fundamentals of sound radiation, and on efficiency, sensitivity and transmission. The final chapter discusses transducers employing electric resistances. The translators have produced a translation relatively free of the stilted style too common in translations of technical works.

Economic Geography of Industrial Materials, edited by Albert S. Carlson. 494 pages, illustrations, 6¾ × 10 in. New York, Reinhold Publishing Corp., 1956. Price, $12.50.

Twenty-seven experts have contributed to this volume to help the industrialist plan economical production and bigger profits, to guide him in selecting a site for a new plant, and to aid him in anticipating changes in supply and demand. Each of the 22 chapters covers one aspect of the five main divisions of the book: resources and transportation; fuel and power for industry; products from minerals; natural and synthetic products; and agricultural and food products. Each chapter contains tables, charts, graphs, maps and statistics bearing on the economic problems treated. The handbook should prove a valuable source of reference for management in almost any industry. Unlike some handbooks, this one is well printed in good-sized type, on coated stock, so that the text is readable and the illustrations clear.

METHODS OF MATHEMATICAL PHYSICS, by Sir Harold Jeffreys and Bertha Swirles (Lady Jeffreys). Third edition, 714 pages, diagrams, $7\frac{1}{2} \times 10\frac{1}{4}$ in. New York, Cambridge University Press, 1956. Price, $15.00.

A third edition in 10 years speaks well for the worth of this volume. This latest revision includes an elementary proof of the theorem of bounded convergence for Riemann integrals. Several other proofs have been added, some theorems restated in more explicit terms, and the proof of Poisson's equation has been improved. The discussion of the Airy integral for complex argument has been expanded, as has the discussion of the confluent hypergeometric function, in which the analytic continuation of the solutions has been applied to parabolic cylinder functions. With the further correcting of original misprints, this third edition should replace earlier ones in the libraries of mathematical physicists.

AUTOMATIC PROCESS CONTROL FOR CHEMICAL ENGINEERS, by Norman H. Ceaglske. 228 pages, diagrams, 6×9 in. New York, John Wiley & Sons, Inc., 1956. Price, $6.75.

Written for the chemical engineers, this is the first elementary book to apply basic mathematical principles to chemical process control. The author presents "automation" in the light of chemical engineering, for undergraduate chemical engineering students, and he hopes to stimulate in those students a desire for further study of automatic process control. Seven chapters cover introductory material on automatic control, various control systems, the derivation of equations used in control systems, standard methods of solving differential equations, transient analysis, frequency response and analysis of simple control systems. Problems follow each chapter and an appendix gives a glossary of terms.

THE PHYSICAL WORLD, by Paul McCorkle. Second edition, 465 pages, illustrations, 6×9 in. New York, McGraw-Hill Book Co., Inc., 1956. Price, $5.25.

In the second edition of this elementary physical science college text, the chemistry section has been completely rewritten, the astronomy material has been brought up-to-date, and the nuclear physics and electron physics chapters have been completely rewritten. In addition, laboratory experiments have been added and some new illustrations have been used. Intended for use in a terminal course in the physical sciences, the revised, up-to-date edition will be of more use to the students than the 1950 version.

MOLECULAR BEAMS, by K. F. Smith. 133 pages, diagrams, $4 \times 6\frac{1}{4}$ in. London, Methuen & Co. Ltd.; New York, John Wiley & Sons, Inc.; 1955. Price, $2.00.

Another of the Methuen Monographs on Physical Sciences, this little book covers the three decades of work on molecular beams. In six concise chapters, the author covers the essentials of the production, measurement, characteristics and uses of molecular beams. The first Methuen Monograph on this subject was published in 1937; the present volume, although bearing the same title, is essentially a new book, since the resonance method which transformed existing techniques was introduced after the first book was published.

BOUNDARY LAYER THEORY, by Hermann Schlichting, translated by J. Kestin. 535 pages, $6\frac{3}{4} \times 9\frac{1}{4}$ in. New York, McGraw-Hill Book Co., Inc., 1955. Price, $15.00.

This translation and revision of the German edition was written to satisfy the demand for an up-to-date, comprehensive presentation of the subject branch of fluid dynamics. New material is introduced in Chapter XXII on turbulent boundary layers with pressure gradients and Chapter XV on compressible boundary layers.

Emphasis is on the fundamental physical ideas rather than on mathematical refinement, with theoretical analyses supplemented with pertinent experimental data. The book was written for aeronautical engineers in research and industry and for students of mechanical engineering and machine design. Chemists and physicists who deal with problems of fluid flow should also find it useful.

Electrofax Dry-Photographic Enlarger.—A new type of dry-process enlarging printer, capable of reproducing fifteen standard-size engineering drawings a minute from microfilm originals, was demonstrated for the first time recently by the Radio Corporation of America before representatives of business, industry and the Armed Forces.

The high-speed, automatic enlarger-printer, which is expected to revolutionize the storage and reproduction of vital engineering drawings, is the first commercially designed machine to utilize the RCA-developed Electrofax dry-photographic process, according to Arthur L. Malcarney, General Manager, RCA Commercial Electronic Products.

The RCA Electrofax machine, Mr. Malcarney pointed out, is the first enlarger printer designed for use with the Dexter-developed Filmsort system—a relatively new method for filing and selecting drawings for reproduction. Filmsort utilizes individual exposures of drawings on microfilm. Each exposure or microfilm frame is mounted on a separate electric accounting machine card to provide maximum freedom and speed of selection. This is in contrast with conventional methods of copying drawings full-scale for filing, or recording them on continuous rolls of microfilm. The Filmsort cards can be selected quickly according to category by conventional electric punch-card machines. The RCA Electrofax machine also processes 35-mm. roll microfilm.

The integrated system of Filmsort equipment, for microfilm filing and finger-tip availability of needed drawings, and the RCA Electrofax enlarger-printer, for "short-order" reproduction, Mr. Malcarney said, promises new speed, efficiency, and economy to virtually all high-volume processors of engineering drawings.

The reproduction system will:

1. Eliminate need for storing space-taking full-size originals at stations or departments where copies may be required.

2. Make working-size copies of original drawings available in less time, and at less over-all cost, than is possible with any existing photo-reproduction system.

3. Facilitate the handling of rush orders for copies and appreciably increase the daily processing potential.

4. Permit the centralization of vital engineering drawings in a master file for maximum security and preservation.

The Electrofax machine, which is push-button operated, has an automatic focus, reproduces standard A, B, and C-size drawings in full scale and larger drawings in half-size; and can be pre-set to reproduce up to 500 microfilm originals at one loading, with up to 24 multiple copies of each.

The RCA Electrofax enlarger-printer can be loaded with up to 500 Filmsort microfilm cards, or with standard 100-ft. reels of 35-mm. positive microfilm. The cards are loaded in a rack above the lens system and automatically dropped in front of the lens at the rate of one every four seconds. The roll film, which is fed automatically and hori-

zontally in front of the lens, is inserted in much the same manner that a typewriter ribbon is installed. At the press of a button, the microfilm originals—cards or roll—are fed into the lens system automatically, at a rate of one frame every four seconds.

The development utilizes both the special printing paper and the magnetic "brush" developing technique devised by scientists at the David Sarnoff Research Center of RCA, Princeton, N. J., for high-speed electronic photo-printing on any solid surface. The paper, a commercial-type stock coated with an electro-sensitive material, is automatically electrostatically sensitized as it is processed inside the machine. The paper is inserted in the machine in rolls 22 in. wide, 15 in. in diameter, and approximately 3500 ft. long.

The paper, which is several thousand times faster than blue-print paper, operates automatically at a speed of 23 linear feet per minute. The paper is exposed by the light images of the microfilm originals as they are processed through the lens and projection system. When the charged paper is exposed, its electrostatic charge in the areas exposed to light is reduced, leaving a latent image in the non-exposed areas. The latent image is then "developed" by the automatic passage of magnetic "brushes," across the exposed paper. The "brushes" consist of a mass of iron filings mixed with a pigmented resin powder carrying a positive electrostatic charge. When the magnetic "brushes" sweep across the exposed paper, their positively charged powder clings to the negatively charged areas of the exposure. The original image is revealed instantly as the particles cling to the negative areas of the latent image.

The developed image is fixed permanently as the paper moves through a dry temperature "bath" which causes the powder to bind itself to the coated surface of the paper. The fixed exposure becomes a bonded, non-fading image.

The treated paper rolls forward to the machine's output mechanism which winds the finished engineering drawing reproductions on an output roll. The reproductions can be cut from the roll as needed.

The entire process, from loading the negatives to rolling up the finished drawings, is completed at a speed rate of one film frame every four seconds. A full load of 500 Filmsort cards can be processed within 35 minutes to provide 500 C-size (17 by 22-in.) reproductions.

Operation is from a single centralized push-button control panel. A feature of the control operation is a series of panel buttons which light up to indicate trouble-spots in any major operating area of the system.

Integrated Flight Instrument System.—The first Integrated Flight Instrument System, a new concept in flight efficiency, safety and control has just been developed by Kollsman engineers. For the first time airline pilots are given interrelated flight data which are, moreover, more precise and more complete than any available to date. The System features greatly increased altimeter accuracy to provide precision in altitude separation. Douglas Aircraft Co., Inc. has announced its acceptance of the instrumentation for use in the DC–8 aircraft.

Designed for all high performance transport aircraft to meet the demands of major airlines, the new Kollsman Integrated Flight Instrument System is a significant step

toward solving the problems of altitude separation, cruise control and navigation dead reckoning.

The important advantage of the system is that it depends on conventional pressure instruments which are connected electrically to each other and to a computer but which can function independently. By means of this electrical connection, standard indications are made considerably more accurate and new information is secured. In the event of electrical interruption, the pilots continue to receive pressure readings so that indicated and maximum allowable airspeed and Mach number are not affected, while altimeter indication reverts to its normal pressure accuracy.

Along with corrected altitude, Mach number, and indicated and maximum allowable airspeed, the System presents to the airline pilots important information not available before—minimum safe speed for approach and landing, most efficient cruising speed, and true outside air temperature used in detecting and flying the jet streams. True airspeed is also given directly so that involved computations are not required.

The nucleus of the System is an altimeter which has a new high accuracy with realistic errors of not over 50 ft. at sea level and 100 ft. at 40,000 ft. Designed for easy readability, the altimeter registers thousands of feet on a counter or drum, and shows hundreds of feet with a pointer.

Airspeed is indicated on the familiar pressure instrument with a range of 60 to 450 knots. Minimum safe speed and most efficient cruising speed are represented on a colored arc which moves around the rim of the dial face. Maximum allowable airspeed for the entire range of the aircraft is shown by a striped pointer, and indicated airspeed, by the main pointer. True airspeed is presented separately on an easy-to-read digital counter type dial.

The Kollsman Machmeter, which is corrected for installation error, gives a continuous indication of Mach number and has a range from 0.3 to 1.0 Mach number and from sea level to 50,000 ft.

True outside air temperature is indicated directly. Previously, even to approximate the true reading, pilots had to apply corrections to the indicated outside air temperature. In addition, the System can provide remote true airspeed and true outside air temperature for the navigator.

The Kollsman Integrated Flight Instrument System consists of three pressure instruments—a sensitive altimeter, a standard indicated airspeed instrument and a Machmeter. The System also includes an angle of attack sensor, an outside air temperature probe, and a computer. By means of servo components the instruments are interconnected to each other and to the computer. Information signaled from one instrument is used to correct the data of other instruments.

While there are only five sensing units, each one carries out more than one function. For example, both Mach number and angle of attack data are fed into the altimeter to correct for the inherent error in the aircraft's static pressure system. To correct for instrument error, information from the altimeter is servoed to the computer where it is acted upon by a scale error corrector and the precise correction is fed back to the altimeter. Moreover, by combining Mach number with outside air temperature, true outside air temperature and true airspeed are obtained. In-

formation from the angle of attack sensor is fed to the airspeed indicator where the minimum safe speed and most efficient speed are presented.

The development of the Kollsman Integrated Flight Instrument System is considered one of the major contributions to commercial aviation in recent years. Although designed primarily to meet the critical demands of jet transports, it is equally well suited to every type of high performance aircraft.

Deepfreeze Radio Broadcasts Behind Volcano.—Mount Erebus, Antarctica, is one of the earth's few remaining active volcanoes. The main communication station at McMurdo Sound will attempt to transmit over the 13,200 foot volcano to Washington, D. C., a distance of 12,000 miles. The mineral content of the mountain is not known. If transmission is unsuccessful over Mount Erebus, the rhombic antenna at McMurdo Sound will be reversed and transmission to Washington, D. C., accomplished in the opposite direction. McMurdo Sound is approximately 600 miles west of Little America and an important station on the OPERATION DEEPFREEZE expedition.

Electronic Scanner Locates Brain Tumor.—A new electronic scanning device which aids in locating brain tumors was described to engineers attending the Institute of Radio Engineers annual convention. The apparatus detects the amount of radiation given off by radioactive tracers introduced into the brain and converts it into a picture of the tumor location. Abnormalities such as tumors or abscesses appear as regions of increased concentration of tracer material. The equipment makes use of scintillation counters which mechanically scan the patient's head and automatically print a record of tracer concentration.

Electronic Computer Helps Detect Cancer Cells.—An electronic scanning and computing device which can perform some functions of the human eye and brain to distinguish between normal and cancer cells was disclosed recently at the opening session of the Institute of Radio Engineers four-day annual convention. The device, called a cytoanalyzer, scans the microscope images of the cells, automatically sorts them in its "mind" according to their characteristics, and classifies them as normal or suspicious.

W. E. Tolles, H. S. Sawyer and R. C. Bostrom of Airborne Instruments Laboratory told fellow engineers at the Waldorf-Astoria Hotel that the instrument could collect and record in a matter of minutes more cell measurements than a technician using the usual manual methods could obtain in as many months. The device is part of a larger instrument for automatic screening of slides for the early detection of cancer now being developed at Airborne Instruments Laboratory under the sponsorship of the American Cancer Society and the National Cancer Institute of the U. S. Public Health Service.

The cytoanalyzer consists of a scanning element which converts the cell images into electrical signals, and a computer which applies rules of logic, much as a technician would, to recognize true cell signals and reject signals that have no diagnostic value. The accepted signals are then recorded on an electronic graph that in effect sorts the individual cells according to their characteristics.

This computer technique is ex-

pected to prove helpful also in obtaining information about the growth of cells and the functioning of the heart and brain.

Iron Rust Improves Radar Equipment.—Rust on automobiles or steam boilers serves no useful purpose. It is unsightly and causes impaired or even hazardous operation. However, in radar, television and guided-missile control equipment, iron rust in the form of ferrites plays a useful role. Ferrites, or ceramic substances made up from oxides of iron and other metals, were discussed in several papers presented to more than 40,000 engineers and scientists on the third day of the Institute of Radio Engineers 44th annual convention, March 19–22.

Ferrite isolators provide one-way windows for radar. This is easy because of the microwave frequencies used for radar, radio waves behave much like light. However, ferrite windows are better than the one-way glass windows used in hospitals and doctors' offices. The ferrite windows can be made to look first one way and then the other.

In a radar set, the ferrite window is initially set to pass the powerful transmitter pulse out to the antenna. Then current is reversed in a coil surrounding the ferrite and the window looks the other way to receive the low-level echo returning from the target. This keeps the strong transmitter pulse from damaging the delicate receiver and prevents the echo from becoming lost in the transmitter.

New radar sets have dual transmitting antennas. This enables the equipment to see out of two eyes as a human being does. Ferrite windows rapidly switch power between antennas to give the effect of continuous bioptical sight.

Tiny ferrite rods can themselves be used as radar antennas, another paper reports. When a group of these tiny rods is used and the radar power rapidly switched from one rod to another, the radar beam scans its target like a searchlight. However, using the ferrite rods, the giant radar reflector can be kept stationary throughout the scanning process. This may remove the need for powerful drive motors and will permit more rapid scanning of the target area.

Radar Predicts Radio Preception.—The Signal Corps Engineering Laboratories have developed a new technique for exploring UHF and microwave transmissions beyond line-of-sight which is expected to result in a great increase in the use of these frequencies. Using a standard Army radar set and unique photographic processes, a map is produced in a few minutes which shows the areas in which communication is possible from any given sight. Maps made at Fort Monmouth show that at ranges of 5 or 10 miles it is often possible to communicate by microwaves over paths obstructed by hills, trees or buildings. Using the radar-photographic technique these paths can be located instantly, eliminating expensive time consuming point by point surveys.

In an address to the Institute of Radio Engineers annual convention, R. E. Lacy and C. E. Sharp of the Signal Corps Engineering Laboratories reported they are now using the technique to expedite radio propagation research needed for the National Defense. The technique may also be used for sight surveys for television, mobile police, fire and taxicab radio services and for radio relay circuits.

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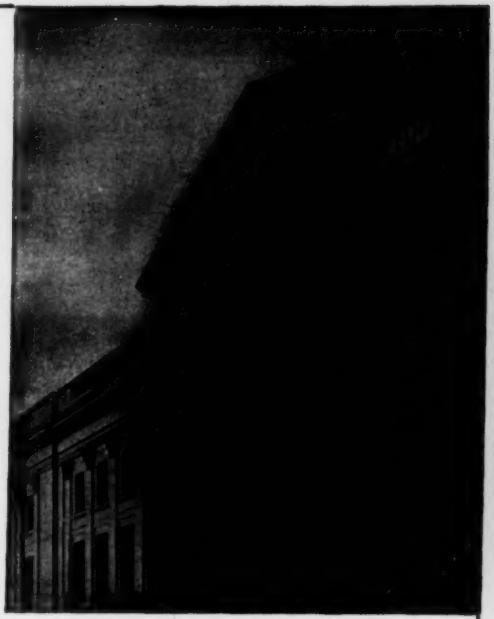

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